GENERALISED SOLUTION
FOR
CIRCULAR PLATES ON ELASTIC FOUNDATIONS

A THESIS

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By
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CERTIFICATE

This is to certify that the thesis entitled "GENERALISED SOLUTION FOR CIRCULAR PLATES ON ELASTIC FOUNDATIONS" is a record of work carried out under my supervison and that it has not been submitted elsewhere for a degree.

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SYNOPSIS

of the
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"GENERALISED SOLUTION FOR CIRCULAR PLATES ON ELASTIC FOUNDATIONS"

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MASTER OF TECHNOLOGY IN MECHANICAL ENGINEERING

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In the present work the author has developed a method of analysis in polar co-ordinate system, for a loaded circular plate on an elastic foundation by using finite difference technique. The subgrade has been assumed as semi-infinite elastic isotropic homogenous material. No assumption regarding the contact pressure distribution has been made. The equations have been developed in non-dimensional form and the results also have been obtained in non-dimensional form. The deflections are assumed to be small and the plate is assumed to be thin.

The results have been compared with some experimental results given in Reference 6. The aggrement is quite good. The problem has been solved for a single concentrated load at various radial positions various values of $\bar{D}$ & μ. This is the most general case of loading and the results for any particular case of loading can be obtained from the results of the present method by proper superimposition. To show how to do this a few

particular cases of loadings have been solved.

Finally the results have been presented in the form of polynomial equations involving the various independent variables of the problem. The co-efficients have been tabulated and the method of using this co-efficients to get the deflection for any particular case have been discussed. Using these co-efficients, the deflections for any particular case can be obtained by using a small digital computer or even a desk calculator.

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NOMENCLATURE

w	=	Deflection of the plate and the subgrade
$\bar{w}$	=	Non-dimensional deflection of the plate and the subgrade
M_ρ	=	Radial component of moment
$\bar{M}_\rho$	=	Radial component of non-dimensional moment
$\bar{M}_\theta$	=	Tangential component of non-dimensional moment
$M_{\rho.\theta}$	=	Twisting moment
E_p	=	Young's modulus of the plate material
E_s	=	Young's modulus of the subgrade material
μ	=	Poission's ratio of the plate material
ν	=	Poisson's ratio of the subgrade material
h	=	Thickness of the plate
q	=	Loading on the plate
$\bar{q}$	=	Non-dimensional loading on the plate
p	=	Reactive pressure from the subgrade
M_θ	=	Tangential component of moment
D	=	Flexural rigidity of the plate
$\bar{D}$	=	Non-dimensional flexural rigidity of the plate subgrade combination

Other notations used are described as and when used.

CHAPTER I

INTRODUCTION

1.1 Introduction

The study of plates on elastic foundation has an important application in foundation engineering. It is a formidable hurdle for engineers even today to arrive at an economical and rational basis of design for cirular raft foundations. In the present analysis a method of solution has been discussed which is perfectly general in the sense that the results obtained by this can be used to solve problems of circular plates on elastic foundations for any type of loading by proper superimposition. This problem occurs in practice in the foundation of water towers, chimnies, silos and similar structures.

The assumptions on the basis of which the present formulation has been done are:

i) The subgrade is assumed to be a semi-infinite, elastic, isotropic homogeneous solid. This is a very common assumption made for subgrade and in the case of normal structures under small settlement conditions this gives a realistic picture of the actual

stress condition. Another common assumption about the subgrade which has been used by many investigators is that of dense liquid subgrade, where it is assumed that the reactive pressure at any point is directly proportional to the deflection of the subgrade at that point. In this assumption the lateral continuity of the soil mass is ignored. Preferance has been given to the elastic isotropic solid assumption over the dense liquid assumption because it gives a more realistic picture of the actual subgrade though it has been seen that the latter assumption gives quite agreeable solution in some cases.

ii) It is assumed that the theory of thin plates is applicable to the plate under consideration and thus the basic limitations of the plate theory are also applicable to the present problem.

iii) The plate is assumed to remain always in contact with the subgrade. This obviously implies that there must be some adhesive force to keep the plate from lifting. In practice the weight of the plate and the overlying mass of soil prevent lifting of the plate from the subgrade.

iv) The shear force at the interface of the plate and the subgrade has been neglected. This shear force which is developed owing to sliding tendency between the plate and the subgrade will be of very small magnitude and as such will have very little effect on the deflected shape of the plate.

v) The external moments at the loading points have been neglected.

vi) Deflections are small.

The main merit of the present method is that no assumption regarding the nature of contact pressure distribution is necessary. Equations have been formulated eliminating this unknown pressure distribution from the condition of equilibrium and compatibility of the forces and deflected shape of the plate and the subgrade surface.

1.2 Review of Past Work

The subject of plates on elastic foundations has received engineers' attention mostly since the second quarter of this century. Both plates and beams on elastic foundations constitute a vast field of study. A rather less intensive study has been devoted so far to the bending of plates on elastic foundations than to beams.

The contribution to the problem of plates on elastic foundation can be subdivided into three major groups, according to the different subgrade assumptions made in the analysis. These are:

i) The first group assumes the subgrade to have a constant subgrade modulus, i.e., the deflection of the elastic foundation at any point of the surface is directly proportional to the pressure at that point and is independent of pressures at other points.

Mathematically it can be expressed as

$$P = Kw$$

where

P = Reactive pressure

K = Constant subgrade modulus

w = Deflection of subgrade

This assumption, obviously ignores the lateral link in the semi-infinite continuum. Physically this model can be interpreted as a system of mutually independent separate springs with the same linear elastic properties. This occurs in practice in a dense liquid, on which structures remain in a floating condition.

ii) A second kind of assumption for the subgrade which has been taken by many investigators and accepted by the author in the present analysis is that of a semi-infinite isotropic homogeneous elastic solid. In this case the deflection of a particular point of the subgrade is dependent not only on the pressure at that particular point, but also on the pressure at all other points of the subgrade.

Obviously, this assumption presents a rather complicated mathematical barrier. But engineers have many a time accepted this trouble by including in their analysis this logical assesment of the subgrade properties.

iii) The third group includes various kinds of assumptions other than the two described above, e.g., elastic layer system,

anisotropic behaviour, elastic properties varying with depth, composite layer foundation etc.

Incidentally, the first type of assumption as stated above was made by Winkler[36]. This assumption, despite its limitations, leads to good results for many practical problems such as floating bridges, floating ice ferries where the relation P = Kw represents a simple consequence of the law of Archimedes, as well as in the case of plates and beams resting on a sufficiently thin deformable layer. Pickett[27] has commented that, when the subgrade is an elastic layer of finite thickness, and is supported by a base of much more rigid material, then for bearing plates of diameter larger than the thickness of the elastic layer, the effect of the subgrade on the bearing plate will be more nearly like dense liquid than that of semi-infinite elastic solid. With this model of foundation a rapid development of the field of plates on elastic foundations occurred after the second world war, particularly to cope up with the problem of designing concrete road pavements and aircraft runways. A large amount published work[7,11,13,21,24,27,34,35] appeared, mainly concerned with furnishing engineers with practical design methods. But most of these works concern with infinite slab loaded with a concentrated force or a patch load. These works were mainly carried out in U.S.A. at different Highway Research Institutes.

A large number works with the same assumption of dense liquid have been published in many other countries, particularly U.S.S.R., Japan and Germany. A comprehensive review of the works

done in Russia is given by Korenev[21,22]. A series of papers by Atsushi Saito et.al.[1,2] have dealt with the solution of finite circular plates with help of infinite series involving Ber, Bei, Ker and Kei functions.

In the third group first comes Reisnerr foundation[28,29]. In this case the subgrade is assumed as a vertically loaded elastic layer in which the horizontal stress components are neglected. Rhines[29] points out that this model may predict excessive stresses in the structure because this is not very realistic for relatively thick foundation layer.

Next comes the Hetenyi foundation[14,15,16]. Here the subgrade is represented by two sets of springs with two different spring constants and a fictitious member in between them. In this case an arbitrary degree of discontinuity may be allowed for the subgrade. This assumption has been applied to plates on elastic foundation by Lee[23].

Here it should be noted that the Reissner foundation leads to a sixth order differential equation and Hetenyi foundation leads to an eighth order differential equation. Though this provides greater adaptibility, while solving them mathematically they become very much complicated.

With elastic isotropic solid subgrade assumption, probably Hogg[17] and Holl[18] had been the first to publish their works in 1938. They have independently solved the problem of a thin slab of semi-

infinite dimension supported by a semi-infinite elastic subgrade.

Pickett and Badruddin[26] has given some influence charts for design of semi-infinite pavement slabs with this assumption.

In a more recent work Chatterjee and Ghosh[6] have solved the case of a circular plate on elastic foundation for six equally spaced concentrated loads. The present work is a generalisation of their work.

A comprehensive review of the various foundation models has been given by Kerr[20].

In the present analysis the subgrade has been assumed as a semi-infinite homogeneous, isotropic elastic body. Because as pointed out earlier Winkler's assumption neglects completely the lateral continuity of the soil mass and the models of the third group are very complicated mathematically. The reason for avoiding complicated mathematics being that the purpose of the present analysis is to provide engineers with a sound method of design of circular plates on elastic foundations.

1.3 Object and Scope of the Present Work

The main object of the present analysis is to find a method of solution for circular plates on elastic foundations, which is perfectly general and can be used for any type of loading. The results have been obtained in non-dimensional form so that this solution is valid for any plate material, any type of subgrade material and for any dimension of the plate.

Scientists have idealised the subgrade, though the behaviour of actual subgrade is very much unpredictable even with elaborate soil tests. The assumption of isotropic elastic homogeneous solid is a very common assumption and perhaps the most widely used in solving settlement problems of foundation engineering. Terzaghi[19] pointed out, "if the factor of safety of a mass of soil with respect to failure by flow exceeds a value of about 3, the state of stress computed in the soil is likely to be more or less similar to the stress computed on the assumption that the soil is perfectly elastic. Hence, the state of stress in a mass of soil under influence of moderate stresses can be estimated by means of theory of elasticity". The range of stress and strain in soil underneath normal foundation of a structure will be well below the plastic stato.

Thus, it is obvious that the present work has a potential applicability in the field of "Foundation Engineering".

CHAPTER II

THEORETICAL ANALYSIS

2.1 Mathematical Model and Idealisation

Taking all the assumptions described earlier in Chapter I, the mathematical equation for plates on elastic subgrade[33] is given by

$$D \left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) \left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2}\right) = q(x,y) - p(x,y) \qquad (2.1)$$

where, D = Flexural rigidity of the plate

$$= \frac{E_p h^3}{12(1-\mu^2)}$$

E_p = Modulus of elasticity of the plate material

h = Thickness of the plate

μ = Poisson's ratio of the plate material

w = Deflection of the plate

$q(x,y)$ = Loading pressure on the plate

$p(x,y)$ = Reactive pressure from the subgrade on the plate

Out of all the variables as listed above the only unknowns are w and p(x,y). The reactive pressure p(x,y) depends upon the properties of the subgrade and plate, dimension of the plate and the loading pattern.

The above equation (2.1) when expressed in polar co-ordinate system takes the form

$$D\left(\frac{\partial^2}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2}{\partial\theta^2}\right)\left(\frac{\partial^2 w}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial w}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2 w}{\partial\theta^2}\right)=q(\rho,\theta)-p(\rho,\theta) \qquad \ldots (2.2)$$

where ρ is the radial coordinate and θ is the angular co-ordinate of a point on the plate.

2.2 Approach to Numerical Solution

2.2.1 Finite Difference Expression for Plate Equation

The left hand side of the plate equation is nothing but the biharmonic operator. So to find the finite difference expression of the plate first the polar biharmonic operator is expanded as shown below:

$$\nabla^4=\left(\frac{\partial^2}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2}{\partial\theta^2}\right)\left(\frac{\partial^2}{\partial\rho^2}+\frac{1}{\rho}\frac{\partial}{\partial\rho}+\frac{1}{\rho^2}\frac{\partial^2}{\partial\theta^2}\right)$$

$$=\frac{\partial^4}{\partial\rho^4}+\frac{2}{\rho^2}\frac{\partial^4}{\partial\rho^2\partial\theta^2}+\frac{1}{\rho^4}\frac{\partial^4}{\partial\theta^4}+\frac{2}{\rho}\frac{\partial^3}{\partial\rho^3}-\frac{2}{\rho^3}\frac{\partial^3}{\partial\rho\partial\theta^2}$$

$$-\frac{1}{\rho^2}\frac{\partial^2}{\partial\rho^2}+\frac{4}{\rho^4}\frac{\partial^2}{\partial\theta^2}+\frac{1}{\rho^3}\frac{\partial}{\partial\rho} \qquad \ldots\ldots (2.3)$$

The plate has been divided into elements by radial lines and concentric circles as shown in Fig. 2.1. The points at which the differences are taken are the central point of each element and not the intersection of the grid lines. The reason for this will be pointed out later on.

For the arrangement of elements in polar system as shown in Fig. 2.1 the finite difference expressions[3,9,30] for the various partial derivatives of w in $\nabla^4 w$ for an element I,v are:

$$\left(\frac{\partial w}{\partial \rho}\right)_{I,v} = \frac{w_{I+1,v} - w_{I-1,v}}{2\delta}$$

$$\left(\frac{\partial^2 w}{\partial \rho^2}\right)_{I,v} = \frac{w_{I+1,v} - 2w_{I,v} + w_{I-1,v}}{\delta^2}$$

$$\left(\frac{\partial^3 w}{\partial \rho^3}\right)_{I,v} = \frac{w_{I+2,v} - 2w_{I+1,v} + 2w_{I-1,v} - w_{I-2,v}}{2\delta^3}$$

$$\left(\frac{\partial^4 w}{\partial \rho^4}\right)_{I,v} = \frac{w_{I+2,v} - 4w_{I+1,v} + 6w_{I,v} - 4w_{I-1,v} + w_{I-2,v}}{\delta^4}$$

$$\left(\frac{\partial w}{\partial \theta}\right)_{I,v} = \frac{w_{I,v+1} - w_{I,v-1}}{2\lambda}$$

$$\left(\frac{\partial^2 w}{\partial \theta^2}\right)_{I,v} = \frac{w_{I,v+1} - 2w_{I,v} + w_{I,v-1}}{\lambda^2}$$

$$\left(\frac{\partial^3 w}{\partial \theta^3}\right)_{I,v} = \frac{w_{I,v+2} - 2w_{I,v+1} + 2w_{I,v-1} - w_{I,v-2}}{2\lambda^3}$$

$$\left(\frac{\partial^4 w}{\partial \theta^4}\right)_{I,v} = \frac{w_{I,v+2} - 4w_{I,v+1} + 6w_{I,v} - 4w_{I,v-1} + w_{I,v-2}}{\lambda^4}$$

$$\left(\frac{\partial^3 w}{\partial \rho \partial \theta^2}\right)_{I,v} = \frac{\partial}{\partial \rho}\left(\frac{w_{I,v+1} - 2w_{I,v} + w_{I,v-1}}{\lambda^2}\right)$$

$$= \frac{1}{2\lambda^2 \delta}\Big[(w_{I+1,v+1} - w_{I-1,v+1})$$

$$-2(w_{I+1,v} - w_{I-1,v}) + (w_{I+1,v-1} - w_{I-1,v-1})\Big]$$

$$\left(\frac{\partial^4 w}{\partial \rho^2 \partial \theta^2}\right)_{I,v} = \frac{1}{\lambda^2}\,\frac{\partial^2}{\partial \rho^2}(w_{I,v+1} - 2w_{I,v} + w_{I,v-1})$$

$$= \frac{1}{\lambda^2 \delta^2}\Big[(w_{I+1,v+1} - 2w_{I},_{v+1} + w_{I-1,v+1})$$

$$-2(w_{I+1,v} - 2w_{I,v} + w_{I-1,v})$$

$$+ (w_{I+1,v-1} - 2w_{I,v-1} + w_{I+1,v-1})\Big]$$

Substituting these in the equation (2.3) and using the relation

$$\rho = (I - .5)\,\delta$$

the final form, after simplification, of the biharmonic operator is given by,

$$\nabla^4 w = \frac{1}{\delta^4} \left[\left(1 + \frac{1}{I-.5}\right) w_{I+2,v} + \left(-4 - \frac{4}{(I-.5)^2 \lambda^2} - \frac{2}{(I-.5)} \right. \right.$$

$$+ \frac{2}{(I-.5)^3 \lambda^2} - \frac{1}{(I-.5)^2} + \left. \frac{1}{2(I-.5)^3}\right) w_{I+1,v}$$

$$+ \left(6 + \frac{6}{(I-.5)^4 \lambda^4} + \frac{8}{(I-.5)^2 \lambda^2} - \frac{8}{(I-.5)^4 \lambda^2} + \frac{2}{(I-.5)^2}\right) w_{I,v}$$

$$+ \left(-4 - \frac{4}{(I-.5)^2 \lambda^2} + \frac{2}{(I-.5)} - \frac{2}{(I-.5)^3 \lambda^2} - \frac{1}{(I-.5)^2} \right.$$

$$\left. - \frac{1}{2(I-.5)^3}\right) w_{I-1,v} + \left(1 - \frac{1}{(I-.5)}\right) w_{I-2,v}$$

$$+ \left(\frac{2}{(I-.5)^2 \lambda^2} - \frac{1}{(I-.5)^3 \lambda^2}\right) w_{I+1,v+1}$$

$$+ \left(\frac{2}{(I-.5)^2 \lambda^2} - \frac{1}{(I-.5)^3 \lambda^2}\right) w_{I+1,v-1} + \left(\frac{1}{(I-.5)^4 \lambda^4}\right) w_{I,v+2}$$

$$+ \left(- \frac{4}{(I-.5)^4 \lambda^4} - \frac{4}{(I-.5)^2 \lambda^2} + \frac{4}{(I-.5)^4 \lambda^2}\right) w_{I,v+1}$$

$$+ \left(- \frac{4}{(I-.5)^4 \lambda^4} - \frac{4}{(I-.5)^2 \lambda^2} + \frac{4}{(I-.5)^4 \lambda^2}\right) w_{I,v-1}$$

$$+ \left(\frac{1}{(I-.5)^4\lambda^4}\right) w_{I,v-2} + \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right) w_{I-1,v+1}$$

$$\left. + \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right) w_{I-1,v-1} \right] \quad \ldots\ldots\ldots \qquad (2.4)$$

The above equation (2.4) can be conveniently expressed in a chart form as shown in Chart 1.

2.2.2 Finite Difference Expressions for Moments

The expressions for M_ρ and M_θ in terms of deflections (w) is also expanded in finite difference form as shown below. These will be necessary for calculating M_ρ and M_θ after getting the deflections.

The expressions for M_ρ and M_θ in terms of deflections in polar form are given by,

$$M_\rho = -D\left[\frac{\partial^2 w}{\partial \rho^2} + \mu\left(\frac{1}{\rho}\frac{\partial w}{\partial \rho} + \frac{1}{\rho^2}\frac{\partial^2 w}{\partial \theta^2}\right)\right] \qquad (2.5)$$

$$M_\theta = -D\left[\frac{1}{\rho}\frac{\partial w}{\partial \rho} + \frac{1}{\rho^2}\frac{\partial^2 w}{\partial \theta^2} + \mu\frac{\partial^2 w}{\partial \rho^2}\right] \qquad (2.6)$$

The finite difference form of the above expressions are,

$$(M_\rho)_{I,v} = -D\left[w_{I+1,v}\left(\frac{1}{\delta^2} + \frac{\mu}{2(I-.5)\delta^2}\right) + w_{I,v}\left(-\frac{2}{\delta^2} - \frac{2\mu}{(I-.5)^2\delta^2\lambda^2}\right.\right.$$

$$+ w_{I-1,v}\left(\frac{1}{\delta^2} - \frac{\mu}{2(I-.5)\delta^2}\right) + \frac{\mu}{(I-.5)^2\lambda^2\delta^2}(w_{I,v+1} + w_{I,v-1})\Bigg] \qquad \ldots\ldots \quad (2.7)$$

$$(M_\theta)_{I,v} = -D\Bigg[w_{I+1,v}\left(\frac{1}{2(I-.5)\delta^2} + \frac{\mu}{\delta^2}\right) + w_{I,v}\left(-\frac{2}{(I-.5)^2\lambda^2\delta^2} - \frac{2\mu}{\delta^2}\right)$$

$$+ w_{I-1,v}\left(\frac{1}{2(I-.5)\delta^2} + \frac{\mu}{\delta^2}\right) + \frac{1}{(I-.5)^2\lambda^2\delta^2}(w_{I,v+1} + w_{I,v-1})\Bigg] \qquad \ldots\ldots\ldots \quad (2.8)$$

The above equations in chart form are shown in Charts 2 and 3.

2.3 Formulation of the Theoretical Analysis

The basic method in solving the problem is to find expressions for the deflection pattern of the subgrade in terms of the reactive pressure and the deflection pattern of the plate in terms of the reactive pressure and the external load applied. After getting these two expressions the reactive pressure from the subgrade is eliminated between these and a new expression involving only one unknown, viz, deflection pattern is obtained. This can be done because the deflection patterns of the subgrade and the plate will be the same. The reason for doing this is that in the plate equation (2.2) there are two unknowns, the deflection w and the reactive pressure p.

2.3.1 Development of the Concept of Deflection Co-efficient for Elastic Subgrade, $\gamma(I,J,K)$

When a concentrated load is acting on the surface of a semi-infinite elastic solid, according to Boussinesq[32], the expression

for deflection of a point on the surface at a distance of r from the load point is given by,

$$w = \frac{P(1-\nu^2)}{\pi E_s r} \tag{2.9}$$

where, w = Deflection of the point

P = Concentrated point load

E_s = Modulus of elasticity of the elastic solid

ν = Poisson's ratio of the material

In this subsection only the deflection of the subgrade will be condidered. For solving the present problem the contact area between the plate and the subgrade has been subdivided into 144 elements by radial lines and concentric circles as the plate (Fig. 2.1). The pressure intensity in one particular element has been assumed to remain constant.

Each element is represented by ρ and θ co-ordinates as shown in Fig. 2.2. So the actual co-ordinates of the central point of the $\rho - \theta$ element is given by $\left[(\rho - 0.5)\delta\ ,\ \theta\right]$.

From Fig. 2.3, it is clear that the deflection at the centre of J-n element due to a load intensity of p on the elemental area (shaded) of I-v element, which may be considered as conctrated at the centre of that infinitesimal area, will be given according to equation (2.9) by

$$\delta w_{J-n} = \frac{1-\nu^2}{\pi E_s r}\ p\ r\ d\theta\ dr$$

$$= \frac{1-\nu^2}{\pi E_s}\ p\ d\theta\ dr \qquad (2.10)$$

Since, the pressure intensity on the I-v element has been considered as uniform the deflection at the centre of J-n element due to the load on I-v element will be given by,

$$w_{J-n} = \frac{1-\nu^2}{\pi E_s}\ p \iint dr\ d\theta$$

Now, replacing the pressure intensity by, $\frac{P_{I,v}}{\text{Area of the loaded element}}$, the expression becomes

$$w_{J-n} = \frac{1-\nu^2}{\pi E_s}\ \frac{P_{I,v}}{(I-.5)\,\lambda\,\delta^2} \iint dr\ d\theta \qquad (2.11)$$

where $P_{I,v}$ = Total uniformly distributed load on I-v element.

2.3.2 Definition of the Deflection Co-effecient $\vartheta(I,J,K)$

The right hand side of the above equation (2.11) can be expressed as a constant quantity multiplied by a non-dimensional variable given by,

$$\frac{1}{(I-.5)\,\delta} \iint dr\ d\theta$$

Now this expression of the variable is found to depend on r, which is again dependent on three other independent variables I,J,K. Where I,J are the ρ- co-ordinates of I-v and J-n elements respectively and K

is the difference of their θ co-ordinates, $(n \sim v)$. The above quantity is described as $\gamma(I,J,K)$. Hence $\gamma(I,J,K)$ may be defined as a triple subscripted non-dimensional co-efficient, which when multiplied by the constant, $P_{I-v}\,(1-\nu^2)/\pi E_s \lambda \delta$, depending upon the subgrade properties and the dimensions of the particular problem, gives the deflection of the centre of J-n element due to an uniformly distributed total load of P_{I-v} on I-v element of the subgrade surface.

Thus the equation (2.11) can be written as

$$w_{J-n} = \frac{(1-\nu^2)\,P_{I-v}}{\pi E_s \lambda \delta} \quad \gamma(I,J,K) \tag{2.12}$$

where

$$\gamma(I,J,K) = \frac{1}{(I-.5)\delta} \quad \iint dr\, d\theta \tag{2.13}$$

The integral $\iint dr\, d\theta$ in $\gamma(I,J,K)$ can be expressed as the line integral $\int_c r\, d\theta$ where c is the peripherial line of the I-v element in the clockwise direction and r is the distance of the points on c from the centre of J-n element.

Now if the sides of the I-v element be represented by I, II, III and IV and the corresponding radius vectors by r_I, r_{II}, r_{III} and r_{IV} as shown in Fig. 2.4.then the integral $\int_c r\, d\theta$ takes the form,

$$\int_c r\, d\theta = \int_{\theta_T}^{\theta_S} r_I\, d\theta + \int_{\theta_S}^{\theta_V} r_{IV}\, d\theta + \int_{\theta_V}^{\theta_U} r_{III}\, d\theta + \int_{\theta_U}^{\theta_T} r_{II}\, d\theta$$

........(2.14)

Thus the expression for γ (I,J,K) becomes,

$$\gamma(I,J,K) = \frac{1}{(I-.5)\delta} \int_{\theta_T}^{\theta_S} r_I \, d\theta + \int_{\theta_U}^{\theta_T} r_{II} \, d\theta + \int_{\theta_V}^{\theta_U} r_{III} \, d\theta + \int_{\theta_S}^{\theta_V} r_{IV} \, d\theta \qquad \ldots\ldots.(2.15)$$

The expressions for the variables r_I, r_{II}, r_{III}, r_{IV} are developed in terms of θ as shown below, by using Fig.2.4:

$$r_I = QX = QR + RX$$

From $\triangle$ OQR, $OR = OQ \cos\theta$

$$= (J-.5)\,\delta \cos\theta$$

From $\triangle$ XOR, $RX = \sqrt{OX^2 - OR^2}$

$$= \sqrt{I^2\delta^2 - ((J-.5)\,\delta \sin\theta)^2}$$

$$= \delta\sqrt{I^2 - (J-.5)^2 \sin^2\theta}$$

So the expression for r_I is

$$r_I = \delta\left[(J-.5)\cos\theta \pm \sqrt{I^2 - (J-.5)^2 \sin^2\theta}\right] \qquad (2.16)$$

In an exactly similar way

$$r_{III} = \delta\left[(J-.5)\cos\theta \pm \sqrt{(I-1)^2 - (J-.5)^2 \sin^2\theta}\right] \qquad \ldots\ldots\ldots\ldots. \quad (2.17)$$

Using the properties of triangles the expressions for r_{II} and r_{IV}

are obtained as,

$$r_{II} = \frac{(J-.5)\,\delta\,\sin\,(K+.5)\,\lambda}{\sin\,\left\{(K+.5)\,\lambda + \theta\right\}} \tag{2.18}$$

$$r_{IV} = \frac{(J-.5)\,\delta\,\sin\,(K-.5)\,\lambda}{\sin\,\left\{(K-.5)\,\lambda + \theta\right\}} \tag{2.19}$$

The limits of the integrals in equation (2.15) are expressed as,

$$\theta_S = \tan^{-1}\left[\frac{I\,\sin\,(K-.5)\lambda}{(J-.5) - I\,\cos\,(K-.5)\,\lambda}\right] \tag{2.20}$$

$$\theta_V = \tan^{-1}\left[\frac{(I-1)\,\sin\,(K-.5)\lambda}{(J-.5) - (I-1)\,\cos\,(K-.5)\,\lambda}\right] \tag{2.21}$$

$$\theta_U = \tan^{-1}\left[\frac{(I-1)\,\sin\,(K+.5)\,\lambda}{(J-.5) - (I-1)\,\cos\,(K+.5)\,\lambda}\right] \tag{2.22}$$

$$\theta_T = \tan^{-1}\left[\frac{I\,\sin\,(K+.5)\,\lambda}{(J-.5) - I\,\cos\,(K+.5)\,\lambda}\right] \tag{2.23}$$

Substituting equations (2.16) through (2.19) in equation (2.15),

$$\gamma(I,J,K) = \frac{1}{(I-.5)} \int_{\theta_T}^{\theta_S} \left[(J-.5)\cos\theta \pm \sqrt{I^2-(J-.5)^2\sin^2\theta} \right] d\theta$$

$$+ \frac{1}{(I-.5)} \int_{\theta_U}^{\theta_T} \frac{(J-.5)\sin(K+.5)\lambda}{\sin\{(K+.5)\lambda + \theta\}} d\theta$$

$$+ \frac{1}{(I-.5)} \int_{\theta_V}^{\theta_U} \left[(J-.5)\cos\theta \pm \sqrt{(I-1)^2-(J-.5)^2\sin^2\theta} \right] d\theta$$

$$+ \frac{1}{(I-.5)} \int_{\theta_S}^{\theta_V} \frac{(J-.5)\sin(K-.5)\lambda}{\sin\{(K-.5)\lambda + \theta\}} d\theta \qquad \ldots\ldots\ldots\ldots \quad (2.24)$$

where θ_S, θ_V, θ_U, θ_T are expressed by equations (2.20) through (2.23).

To get the final values of $\gamma(I,J,K)$ by integration it is found that in the first and third integrals there are terms like $\int\sqrt{I^2-(J-.5)^2\sin^2\theta}\,d\theta$ and $\int\sqrt{(I-1)^2-(J-.5)^2\sin^2\theta}\,d\theta$. These can be very easily reduced to the form of a $\int\sqrt{1-b^2\sin^2\theta}\,d\theta$, which is nothing but standard elliptic integral of second kind for which no closed form integral is available. So the first and third integrals have been calculated by numerical integration using Simpson's Rule with 50 divisions.

The second and fourth integrals pose no problem and they can be integrated in closed form. After doing this the final form of $\gamma(I,J,K)$ is obtained as

$$\gamma(I,J,K) = \frac{1}{(I-.5)} \int_{\theta_T}^{\theta_S} \left[(J-.5) \cos\theta \pm \sqrt{I^2-(J-.5)^2 \sin^2\theta} \right] d\theta$$

$$+ \frac{(J-.5)}{(I-.5)} \sin (K+.5)\lambda \left[\log_e \tan \frac{\{(K+.5)\lambda + \theta\}}{2} \right]_{\theta_U}^{\theta_T}$$

$$+ \frac{1}{(I-.5)} \int_{\theta_V}^{\theta_U} \left[(J-.5) \cos\theta \pm \sqrt{(I-1)^2-(J-.5)^2 \sin^2\theta} \right] d\theta$$

$$+ \frac{(J-.5)}{(I-.5)} \sin (K-.5)\lambda \left[\log_e \tan \frac{\{(K-.5)\lambda + \theta\}}{2} \right]_{\theta_S}^{\theta_V} \qquad \ldots\ldots\ (2.25)$$

From equation (2.25) it is observed that $\gamma(I,J,K)$ is a nondimensional quantity.

2.3.4 Numerical Form of the Generalised Equation of Plates on Elastic Foundations

In section 2.3.2 it was seen that the deflection of the central point of J-n element of the subgrade, due to a uniformly distributed total load of $P_{I,v}$ on I-v element of the subgrade, is given by,

$$\Delta w_{J-n} = \gamma(I,J,K) \frac{(1-\nu^2)\ P_{I,v}}{\pi E_s \lambda \delta} \qquad (2.26)$$

The only difference between this equation and equation (2.12) is that here w_{J-n} has been replaced by Δw_{J-n} to signify that it is the deflection due to the reactive load on I-v-th element only.

But pressure on the subgrade acts on the whole of the circular area covered by the plate of which I-v is only a small element. Thus the actual deflection of the centre of the J-n element of the subgrade will be given by the summation of effects of all such I-v elements within the circular area and thus the expression becomes,

$$w_{J-n} = \sum_{I} \sum_{v} \frac{(1-\nu^2)\ P_{I,v}}{\pi E_s \lambda \delta} \gamma(I,J,K) \tag{2.27}$$

Equation (2.27) is the exact form of the deflection of the central point of the J-n element of the subgrade, being loaded by the pressure on the whole of the circular area below the plate. Thus this equation gives the deflection pattern for the subgrade. Now this deflection is exactly equal to the deflection of the central point of the J-n-th element of the plate.

Till now only the deflections of the central points of the elements of the subgrade have been considered. Now the expressions for deflections of the central points of the elements of the plate are to be found out from plate equation.

The deflection of the central point of I-v element of the plate, being loaded by the imposed load on top and by the reactive pressure from the bottom can be obtained by solving the plate equation,

$$D \nabla^4 w_{I,v} = \frac{q_{I,v}}{(I-.5)\ \lambda \delta^2} - \frac{P_{I,v}}{(I-.5)\ \lambda \delta^2} \tag{2.28}$$

where, $q_{I,v}$ = Applied load on plate at the I-v element

$P_{I,v}$ = Total reactive load on the I-v element of the plate

Equation (2.28) gives the deflection pattern of the plate. Here it is assumed that the total applied load, $q_{I,v}$, can be represented by an uniform pressure distribution on the element and same is the case with $P_{I,v}$.

Now using the finite difference form of $\nabla^4 w$ as given by equation (2.4), the equation (2.28) can be expressed as,

$$\frac{(I-.5)}{\delta^4} D\, f(w) = \frac{q_{I,v}}{\lambda\delta^2} - \frac{P_{I,v}}{\lambda\delta^2} \qquad (2.29)$$

where,

$$f(w) = \left(1 + \frac{1}{(I-.5)}\right) w_{I+2,v} + \left(-4 - \frac{4}{(I-.5)^2\lambda^2} - \frac{2}{(I-.5)}\right.$$

$$\left. + \frac{2}{(I-.5)^3\lambda^3} - \frac{1}{(I-.5)^2} + \frac{1}{2(I-.5)^3}\right) w_{I+1,v} + \left(6 + \frac{6}{(I-.5)^4\lambda^4}\right.$$

$$\left. + \frac{8}{(I-.5)^2\lambda^2} - \frac{8}{(I-.5)^4\lambda^2} + \frac{2}{(I-.5)^2}\right) w_{I,v} + \left(-4 - \frac{4}{(I-.5)^2\lambda^2}\right.$$

$$\left. + \frac{2}{(I-.5)} - \frac{2}{(I-.5)^3\lambda^2} - \frac{1}{(I-.5)^2} - \frac{1}{2(I-.5)^3}\right) w_{I-1,v} + \left(1 - \frac{1}{(I-.5)}\right) w_{I-2,v}$$

$$+ \left(\frac{2}{(I-.5)^2\lambda^2} - \frac{1}{(I-.5)^3\lambda^2}\right) w_{I+1,v+1} + \left(\frac{2}{(I-.5)^2\lambda^2} - \frac{1}{(I-.5)^3\lambda^2}\right) w_{I+1,v-1}$$

$$+ \left(\frac{1}{(I-.5)^4\lambda^4}\right) w_{I,v+2} + \left(-\frac{4}{(I-.5)^4\lambda^4} - \frac{4}{(I-.5)^2\lambda^2} + \frac{4}{(I-.5)^4\lambda^2}\right) w_{I,v+1}$$

$$+ \left(-\frac{4}{(I-.5)^4\lambda^4} - \frac{4}{(I-.5)^2\lambda^2} + \frac{4}{(I-.5)^4\lambda^2}\right) w_{I,v-1}$$

$$+ \left(\frac{1}{(I-.5)^4\lambda^4}\right) w_{I,v-2} + \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right) w_{I-1,v+1}$$

$$+ \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right) w_{I-1,v-1} \qquad \ldots\ldots\ldots (2.30)$$

Now by eliminating $P_{I,v}$ between the equations (2.29) and (2.27), the final form of the generalised equation for plates on elastic foundation is given by,

$$\frac{\lambda E_s}{(1-\nu^2)\,\delta} w_{J,n} + \sum_I \sum_v \frac{(I-.5)D}{\delta^4} \gamma(I,J,K)\, f(w) = \sum_I \sum_v \gamma(I,J,K)\, \frac{q_{I,v}}{\lambda \delta^2} \qquad \ldots\ldots\ldots (2.31)$$

2.3.5 Non-dimensional Form of the Generalised Plate Equation

The generalised equation of plate as given by equation (2.31) is not non-dimensional because it contains terms like E_s, D, which are dependent on plate properties and quantities like δ, which depends upon the plate dimension. Now to make the equation (2.31)

non-dimensional both sides of the equation are divided by $(1-\nu^2)/\pi E_s$ to obtain the following equation,

$$\frac{w_{J,n}}{\delta} + \sum_{I}\sum_{v} \frac{D}{\delta^3}\frac{(1-\nu^2)}{\pi E_s}\gamma(I,J,K)\frac{1}{\delta} f(w)\ (I-.5)$$

$$= \sum_{I}\sum_{v}\gamma(I,J,K)\ \frac{(1-\nu^2)\ q_{I,v}}{\lambda\pi E_s\delta^2} \qquad \ldots\ldots \quad (2.32)$$

Now if the following quantities are considered

$$\bar{w} = \frac{w}{\delta} \qquad (2.33)$$

$$\bar{D} = \frac{D}{\delta^3}\frac{(1-\nu^2)}{\pi E_s}$$

$$= \frac{1}{12\pi}\ \frac{E_p}{E_s}\left(\frac{h}{\delta}\right)^3\frac{(1-\nu^2)}{(1-\mu^2)} \qquad (2.34)$$

$$\bar{q}_{I,v} = \frac{q_{I,v}}{E_s\delta^2}\ \frac{1}{\pi\lambda}\ (1-\nu^2) \qquad (2.35)$$

then it can be seen that the quantities $\bar{w}$, $\bar{D}$ and $\bar{q}_{I,v}$ are all non-dimensional. Now let $f(\bar{w}) = \frac{1}{\delta} f(w)$ such that all the terms in $f(\bar{w})$ are terms containing $(w_{I,v})/\delta$, $(w_{I-1,v})/\delta$ etc, then it can be seen that $f(\bar{w})$ is also non-dimensional. So the above equation (2.32) becomes,

$$\bar{w}_{J,n} + \sum_{I}\sum_{v}\bar{D}\ (I-.5)\ \gamma(I,J,K)\ f(\bar{w}) = \sum_{I}\sum_{v}\gamma(I,J,K)\ \bar{q}_{I,v}$$

Equation (2.36) is the non-dimensional form of the generalised plate equation.

2.3.6 Non-dimensional Form of the Moment Equations

In section 2.2.2 it was shown that the moments M_ρ and M_θ per unit length are given by equations (2.7) and (2.8) respectively. By multiplying both sides of these equations by $(1-\nu^2)/\lambda E_s \delta^2$ and defining the following quantities,

$$\bar{M}_\rho = M_\rho \frac{(1-\nu^2)}{\lambda E_s \delta^2} \tag{2.37}$$

$$\bar{M}_\theta = M_\theta \frac{(1-\nu^2)}{\lambda E_s \delta^2} \tag{2.38}$$

the following equations may be obtained

$$\bar{M}_\rho = -\bar{D}\Big[\bar{w}_{I+1,v}\left(1 + \frac{\mu}{2(I-.5)}\right) + \bar{w}_{I,v}\left(-2 - \frac{2\mu}{(I-.5)^2\lambda^2}\right)$$
$$+ \bar{w}_{I-1,v}\left(1 - \frac{\mu}{2(I-.5)}\right) + \frac{\mu}{(I-.5)^2\lambda^2}\left(\bar{w}_{I,v+1} + \bar{w}_{I,v-1}\right)\Big]$$

$$\ldots\ldots\ldots \quad (2.39)$$

$$\bar{M}_\theta = -\bar{D}\Big[\bar{w}_{I+1,v}\left(\frac{1}{2(I-.5)} + \mu\right) + \bar{w}_{I,v}\left(-\frac{2}{(I-.5)^2\lambda^2} - 2\mu\right)$$
$$+ \bar{w}_{I-1,v}\left(\frac{1}{2(I-.5)} + \mu\right) + \frac{1}{(I-.5)^2\lambda^2}\left(\bar{w}_{I,v+1} + \bar{w}_{I,v-1}\right)\Big]$$

$$\ldots\ldots \quad (2.40)$$

The quantities $\bar{M}_\rho$ and $\bar{M}_\theta$ are non-dimensional and thus equations (2.39) and (2.40) are the non-dimensional moment equations.

2.3.7 Boundary Conditions

In the present problem the boundary of the plate is assumed to be free. For this case the boundary conditions are,

$$M_\rho = 0 \tag{2.41}$$

$$Q_\rho = 0 \tag{2.42}$$

$$M_{\rho\theta} = 0 \tag{2.43}$$

at the edges.

Kirchoff found that the third condition is a superfluous one, and can be combined with the second. Thus the two boundary conditions for the present problem can be expressed as,

$$(M_\rho)_{\rho=a} = -D\left[\frac{\partial^2 w}{\partial\rho^2} + \mu\left(\frac{1}{\rho}\frac{\partial w}{\partial\rho} + \frac{1}{\rho^2}\frac{\partial^2 w}{\partial\theta^2}\right)\right]_{\rho=a} = 0$$

$$\ldots\ldots\ldots \quad (2.44)$$

and, $$(V)_{\rho=a} = \left(Q_\rho - \frac{1}{\rho}\frac{\partial M_{\rho\theta}}{\partial\theta}\right)_{\rho=a} = 0 \, .$$

or, $$-D\left[\frac{\partial^3 w}{\partial\rho^3} + \frac{1}{\rho}\frac{\partial^2 w}{\partial\rho^2} - \frac{1}{\rho^2}\frac{\partial w}{\partial\rho} - \frac{(3-\mu)}{\rho^3}\frac{\partial^2 w}{\partial\theta^2} + \frac{(2-\mu)}{\rho^2}\frac{\partial^3 w}{\partial\rho\,\partial\theta^2}\right]_{\rho=a} = 0$$

$$\ldots\ldots\ldots \quad (2.45)$$

where $a\delta$ = Radius of the plate. In this particular problem a = 6.

The equations (2.44) and (2.45), when expressed in finite difference form become,

$$\tfrac{1}{2}\, w_{a+2,v} + \left(\frac{\mu}{2a^2\lambda^2}\right) w_{a+1,v-1} + \left(-\tfrac{1}{2} + \frac{\mu}{a} - \frac{\mu}{a^2\lambda^2}\right) w_{a+1,v}$$

$$+ \left(\frac{\mu}{2a^2\lambda^2}\right) w_{a+1,v+1} + \left(\frac{\mu}{2a^2\lambda^2}\right) w_{a,v-1} + \left(-\tfrac{1}{2} - \frac{\mu}{a} - \frac{\mu}{a^2\lambda^2}\right) w_{a,v}$$

$$+ \left(\frac{\mu}{2a^2\lambda^2}\right) w_{a,v+1} + \tfrac{1}{2}\, w_{a-1,v} = 0 \qquad \ldots\ldots \quad (2.46)$$

and, $$\left(1 + \frac{1}{2a}\right) w_{a+2,v} + \left(\frac{2-\mu}{a^2\lambda^2} - \frac{3-\mu}{2a^3\lambda^2}\right) w_{a+1,v-1}$$

$$+ \left(-3 - \frac{1}{2a} - \frac{1}{a^2} - \frac{2(2-\mu)}{a^2\lambda^2} + \frac{(3-\mu)}{a^3\lambda^2}\right) w_{a+1,v}$$

$$+ \left(\frac{2-\mu}{a^2\lambda^2} - \frac{3-\mu}{2a^3\lambda^2}\right) w_{a+1,v+1} + \left(-\frac{2-\mu}{a^2\lambda^2} - \frac{3-\mu}{2a^3\lambda^2}\right) w_{a,v-1}$$

$$+ \left(3 - \frac{1}{2a} + \frac{1}{a^2} + \frac{2(2-\mu)}{a^2\lambda^2} + \frac{(3-\mu)}{a^3\lambda^2}\right) w_{a,v}$$

$$+ \left(-\frac{2-\mu}{a^2\lambda^2} - \frac{3-\mu}{2a^3\lambda^2}\right) w_{a,v+1} + \left(-1 + \frac{1}{2a}\right) w_{a-1,v} = 0 \qquad \ldots\ldots \quad (2.47)$$

The equations (2.46) and (2.47) can be written in a chart form as shown in Charts 4 and 5.

To convert these equations to non-dimensional form, what is to be done is simply to divide the equations by δ, so that w's are replaced by $\bar{w}$'s.

2.4 Method of Solution of the Problem

2.4.1 Calculation of γ (I,J,K)

In the present problem the contact area of the circular plate has been divided into 144 elements by 24 radial lines and 6 concentric circles as shown in Fig. 2.1. The extra 48 elements, shown by dotted lines, are auxiliary elements which are needed to get the finite difference equations for the boundary conditions. Since there is no plate at those elements, the γ (I,J,K) values for them will be zero.

While calculating the γ (I,J,K) values on digital computer the value of K is taken as $|n-v| + 1$ instead of $|n-v|$ as a digital computer does not accept a zero or negative subscript in FORTRAN IV language. So in this case the angle between two elements I-v and J-n is (K-1) λ and not Kλ.

From symmetry of the problem along any diameter it is obvious that it is sufficient to calculate γ (I,J,K) for K varying from 1 to 13, because for each J-n element there will be two I-v elements which are symmetrically placed on either side of the diameter passing through the centre of J-n element. The γ(I,J,K) values for these two I-v elements will be the same. So that we will have γ (I,J,K) = γ (I,J,26-K) for K $>$ 1.

2.4.2 Method of Solution for Deflections

The present problem deals with a single concentrated load at the centre of any of the 144 elements of the plate. As will be

clear later, in Chapter 3, this case is the general case of loading and the solution for any particular loading case can be obtained from this solution by proper superimposition.

Again referring to the symmetry of the problem on either side of the diameter passing through the load point it is obvious that the deflection pattern of the plate will also be symmetrical about the same diameter. Thus it is sufficient to solve for the deflection pattern of only half of the plate, viz., for sectors 1 to 13, to describe the deflection pattern of the whole plate.

Now it is possible to write down 78 numbers of equations from the general form of the equation (2.36), one for each of the J-n elements in the sectors 1 through 13. Since the I-v elements are to be summed over the whole of the plate, terms containing deflections of each of the elements including the imaginary elements will be present in each of these equations. Thus each equation will have 104 unknown deflections, viz., the deflections of the 78 real elements and the 26 auxiliary elements. There will be only 104 unknowns and not 192 because it has already been noted that there is a diametral symmetry of the problem. So by using equation (2.36) 78 simultaneous equations in 104 unknowns are obtained. The rest 26 equations are obtained from the two boundary conditions given by equations (2.46) and (2.47), satisfying both of them for each sector. Finally these 104 equations in 104 unknowns are solved on the computer to get the deflections.

The simple basis of the method outlined above, presents great trouble in getting the co-efficients for each of the 104 unknown deflections in each of the equations. To get the co-efficients of each unknown deflection in each equation,it has to be kept in mind that in the basic equation (2.36), the J-n element is taken as the fixed point and the biharmonic part has been written and summed for each of the 192 I-v elements of the plate. So to get the co-efficient for any generalised I-v element, its co-efficients from the different biharmonic equations have to be collected. It may be recollected that in writing the finite difference expansion for the biharmonic euqation about any I-v element, thirteen numbers of I-v elements have to be incorporated. Thus when collecting co-efficient of a particular I-v element in a particular equation all thirteen biharmonic expansions about these neighbouring thirteen points will contribute towards the co-efficient. Keeping this in view, for any generalised element I-v, its co-efficients in collected form can be expressed as,

$$C(I,v) = \bar{D}\Big[(I-.5)\,\gamma(I,J,K)\,\Big(6 + \frac{3}{(I-.5)^4\lambda^4} + \frac{8}{(I-.5)^2\lambda^2}$$

$$- \frac{3}{(I-.5)^4\lambda^2} + \frac{2}{(I-.5)^2}\Big) + (I-2.5)\,\gamma(I-2,J,K)\Big(1 + \frac{1}{I-2.5}\Big)$$

$$+ (I-1.5)\,\gamma(I-1,J,K)\,\Big(-4 - \frac{4}{(I-1.5)^2\lambda^2} - \frac{2}{(I-1.5)}$$

$$+ \frac{2}{(I-1.5)^3\lambda^2} - \frac{1}{(I-1.5)^2} + \frac{1}{2(I-1.5)^3}\Big)$$

$$+ (I+.5)\, \gamma(I+1,J,K)\, \left(-4 - \frac{4}{(I+.5)^2 \lambda^2} + \frac{2}{(I+.5)} - \frac{2}{(I+.5)^3 \lambda^2}\right.$$

$$\left. - \frac{1}{(I+.5)^2} - \frac{1}{2(I+.5)^3}\right) + (I+1.5)\, \gamma(I+2,J,K)\, \left(1 - \frac{1}{I+1.5}\right)$$

$$+ (I-.5)\, \gamma(I,J,K-2)\, \left(\frac{1}{(I-.5)^4 \lambda^4}\right) + (I-.5)\, \gamma(I,J,K-1)$$

$$\left(- \frac{4}{(I-.5)^4 \lambda^4} - \frac{4}{(I-.5)^2 \lambda^2} - \frac{4}{(I-.5)^4 \lambda^2}\right) + (I-.5)\, \gamma(I,J,K+1)$$

$$\left(- \frac{4}{(I-.5)^4 \lambda^4} - \frac{4}{(I-.5)^2 \lambda^2} - \frac{4}{(I-.5)^4 \lambda^2}\right) + (I-.5)\, \gamma(I,J,K+2)$$

$$\left(\frac{1}{(I-.5)^4 \lambda^4}\right) + (I-1.5)\, \gamma(I-1,J,K-1)\, \left(\frac{2}{(I-1.5)^2 \lambda^2} - \frac{1}{(I-1.5)^3 \lambda^2}\right)$$

$$+ (I-1.5)\, \gamma(I-1,J,K+1)\, \left(\frac{2}{(I-1.5)^2 \lambda^2} - \frac{1}{(I-1.5)^3 \lambda^2}\right)$$

$$+ (I+.5)\, \gamma(I+1,J,K-1)\, \left(\frac{2}{(I+.5)^2 \lambda^2} + \frac{1}{(I+.5)^3 \lambda^2}\right)$$

$$+ (I+.5)\, \gamma(I+1,J,K+1)\, \left(\frac{2}{(I+.5)^2 \lambda^2} + \frac{1}{(I+.5)^3 \lambda^2}\right)$$

$$\ldots\ldots\ldots \quad (2.48)$$

To calculate various C(I,v)'s in various equations, by using equation (2.48) the following points have to be kept in mind,

(i) The value of n varies from 1 to 13.

(ii) The value of J varies from 1 to 6.

(iii) The value of I varies from 1 to 8.

(iv) The value of v varies from 1 to 24.

(v) $\gamma(I,J,K)$ for $I > 6$ is zero.

(vi) If $I = 2$ then the term containing $\gamma(I-2,J,K)$ has to be replaced by,

$$(I-1.5)\ \gamma\ (I-1,J,K+12)\ \left(1 - \frac{1}{(I-1.5)}\right)$$

because in that case the (I-2,v) element becomes (I-1,v+12) element.

(vii) If $I = 1$ then

(a) The term containing $\gamma(I-2,J,K)$ has to be replaced by,

$$(I+.5)\ \gamma\ (I+1,J,K+12)\ \left(1 - \frac{1}{I+.5}\right)$$

(b) The term containing $\gamma(I-1,J,K)$ has to be replaced by,

$$(I-.5)\ \gamma\ (I,J,K+12)\left(-4 - \frac{4}{(I-.5)^2\lambda^2} + \frac{2}{(I-.5)} - \frac{1}{(I-.5)^3\lambda^2} - \frac{1}{(I-.5)^2} - \frac{1}{2(I-.5)^3}\right)$$

(c) The term containing $\gamma(I-1,J,K+1)$ has to be replaced by,

$$(I-.5)\ \gamma\ (I,J,K+11)\ \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right)$$

(d) The term containing $\gamma(I-1,J,K-1)$ has to be replaced by,

$$(I-.5)\ \gamma\ (I,J,K+13)\ \left(\frac{2}{(I-.5)^2\lambda^2} + \frac{1}{(I-.5)^3\lambda^2}\right)$$

The co-efficients as obtained by using equation (2.48) have to be properly grouped together by using the symmetry property of the problem. While grouping it has to be kept in mind that from

symmetry of the problem for $I \neq 1$ and $I \neq 13$

$$\bar{w}\,(I,v) = \bar{w}\,(I,26-v) \tag{2.49}$$

After doing the grouping of the co-efficients by using equation (2.49), the co-efficient of the first term $\bar{w}_{J,n}$ in equation (2.38) has to be added to the co-efficient of the proper $\bar{w}\,(I,v)$ in the equation.

Thus 104 simultaneous equations in 104 unknown deflections are obtained. These equations are solved by inverting the co-efficient matrix (this is possible because the matrix is non-singular), using Gauss-Jordan method, to get the deflections of the 104 elements. This is done by varying the load position six times, each time the load being at a different radial position.

Everytime for the sector in which the load is acting, it is assumed, $n = 1$ and $v = 1$, i.e., this is taken as the reference.

The whole method is repeated for five different values of $\bar{D}$ and five different values of μ. Everytime $\bar{q}_{I,v}$ is taken as unity.

Finally the results are given in the form of polynomial equations involving the different independent variables for each sector. The co-efficients have been tabulated. By using the method as described in section 3.4 the deflection pattern for all cases can be determined.

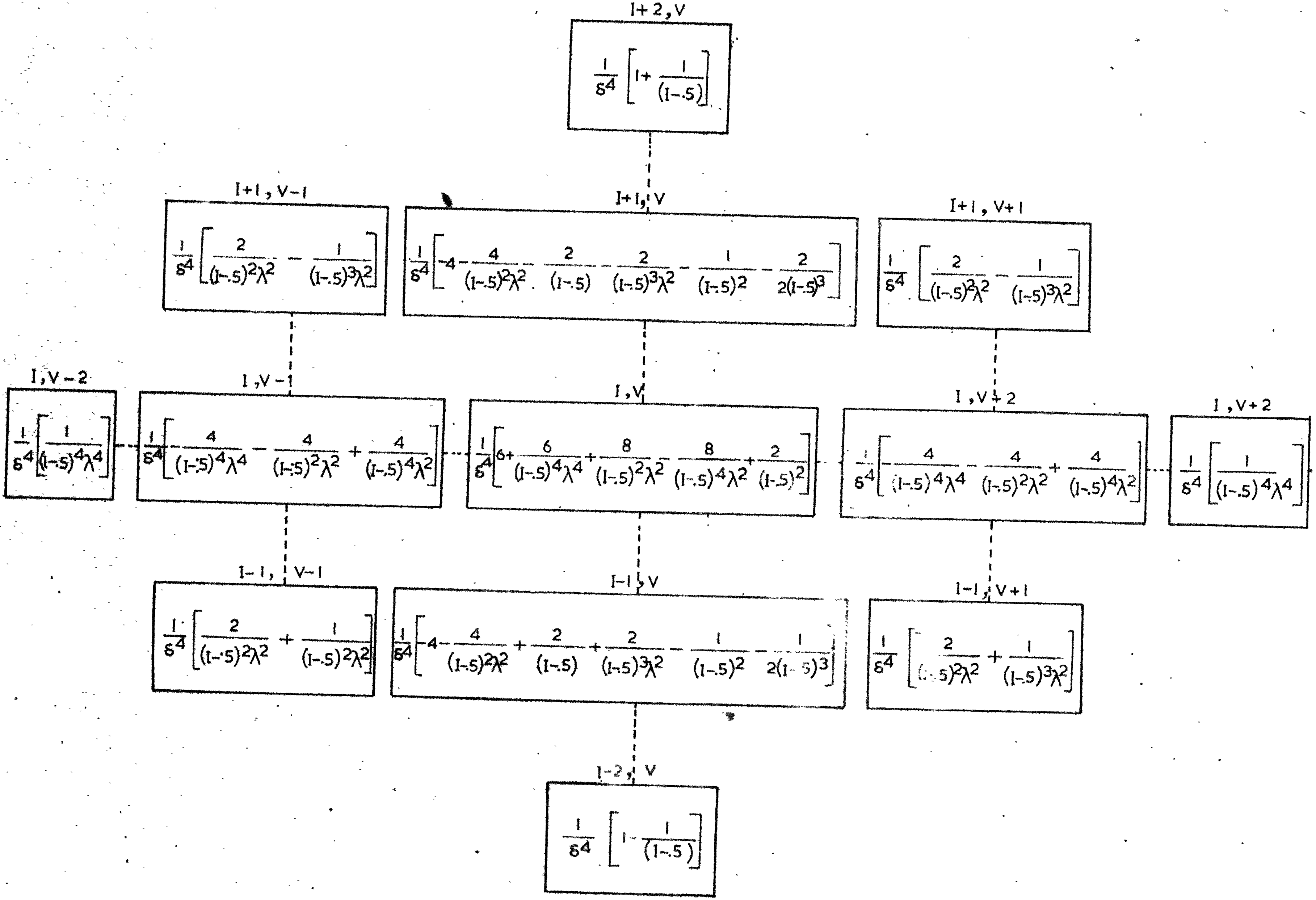

CHART I FINITE DIFFERENCE EXPRESSION FOR ∇^4

I+1, v

$$\frac{1}{\delta^2} + \frac{\mu}{2(I-.5)\delta^2}$$

I, v-1

$$\frac{\mu}{(I-.5)^2\lambda^2\delta^2}$$

I, v

$$-\frac{2}{\delta^2} - \frac{2\mu}{(I-.5)^2\lambda^2\delta^2}$$

I, v+1

$$\frac{\mu}{(I-.5)^2\lambda^2\delta^2}$$

I-1, v

$$\frac{1}{\delta^2} - \frac{\mu}{2(I-.5)\delta^2}$$

CHART 2 - FINITE DEFFERENCE EXPRESSION FOR M_ρ

I+1, v

$$\frac{1}{2(I-.5)\delta^2} + \frac{\mu}{\delta^2}$$

I, v-1

$$\frac{1}{(I-.5)^2\lambda^2\delta^2}$$

I, v

$$-\frac{2}{(I-.5)^2\lambda^2\delta^2} - \frac{2\mu}{\delta^2}$$

I, v+1

$$\frac{1}{(I-.5)^2\lambda^2\delta^2}$$

I-1, v

$$-\frac{1}{2(I-.5)\delta^2} + \frac{\mu}{\delta^2}$$

CHART 3 - FINITE DIFFERENCE EXPRESSION FOR M_θ

	a+2,v $\frac{1}{2}$	
a+1,v-1 $\frac{\mu}{2a^2\lambda^2}$	a+1,v $-\frac{1}{2}+\frac{\mu}{a}-\frac{\mu}{a^2\lambda^2}$	a+1,v+1 $\frac{\mu}{2a^2\lambda^2}$
a,v-1 $\frac{\mu}{2a^2\lambda^2}$	a,v $-\frac{1}{2}-\frac{\mu}{a}-\frac{\mu}{a^2\lambda^2}$	a,v+1 $\frac{\mu}{2a^2\lambda^2}$
	a-1,v $\frac{1}{2}$	

CHART 4- FIRST BOUNDARY CONDITION $(M_\rho)_{\rho=a}$

	a+2,v $1+\frac{1}{2a}$	
a+1,v-1 $\frac{2-\mu}{a^2\lambda^2}-\frac{3-\mu}{2a^3\lambda^2}$	a+1,v $-3-\frac{1}{2a}-\frac{1}{a^2}-\frac{2(2-\mu)}{a^2\lambda^2}+\frac{3-\mu}{a^3\lambda^2}$	a+1,v+1 $\frac{2-\mu}{a^2\lambda^2}-\frac{3-\mu}{2a^3\lambda^2}$
a,v-1 $-\frac{2-\mu}{a^2\lambda^2}-\frac{3-\mu}{2a^3\lambda^2}$	a,v $3-\frac{1}{2a}+\frac{1}{a^2}+\frac{2(2-\mu)}{a^2\lambda^2}+\frac{3-\mu}{a^3\lambda^2}$	a,v+1 $-\frac{2-\mu}{a^2\lambda^2}-\frac{3-\mu}{2a^3\lambda^2}$
	a-1,v $-1+\frac{1}{2a}$	

CHART 5 - SECOND BOUNDARY CONDITION $(V_\rho)_{\rho=a}$

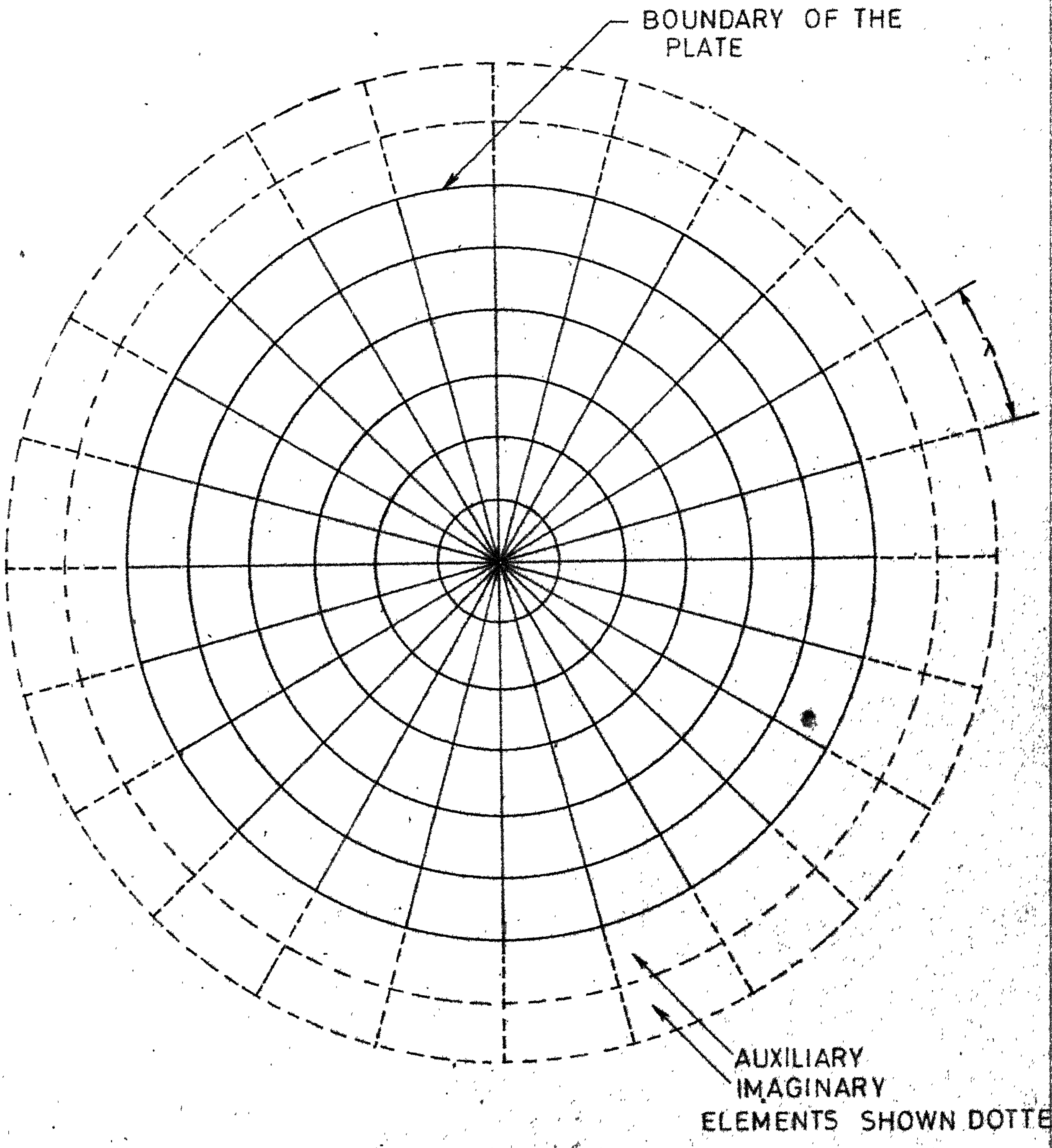

FIG. 2.1 GRID ARRANGEMENTS

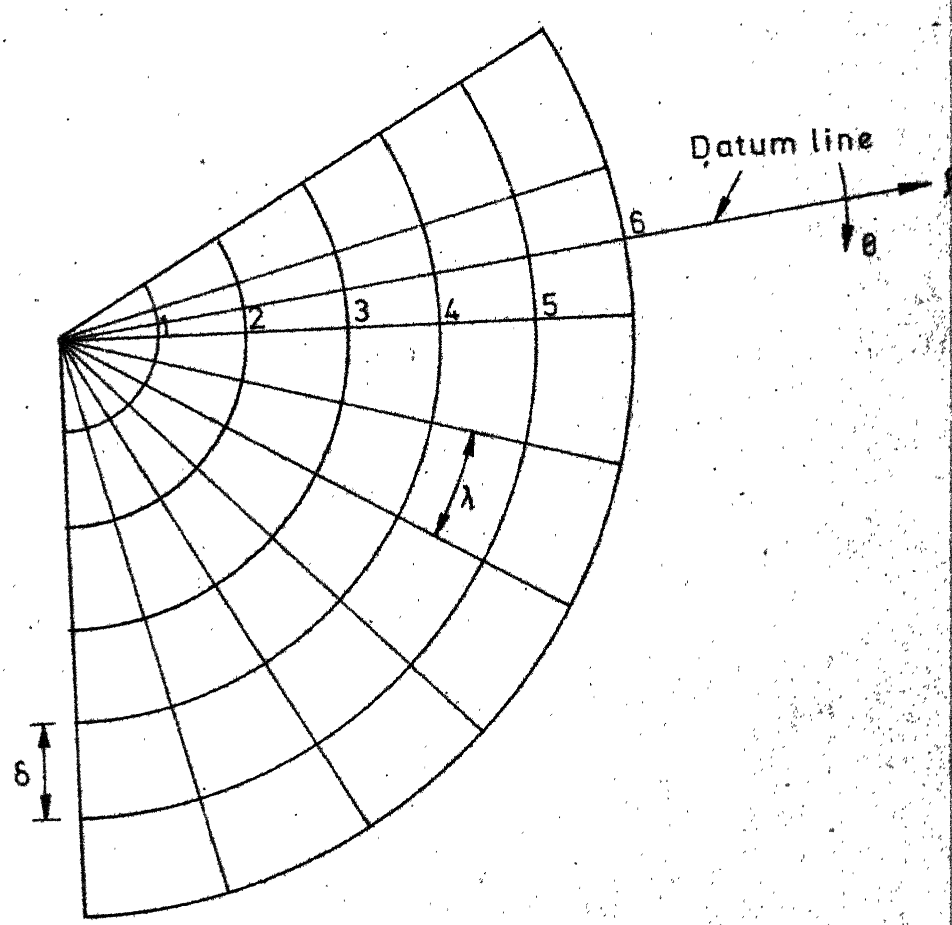

FIG.2.2 CO-ORDINATE SYSTEM

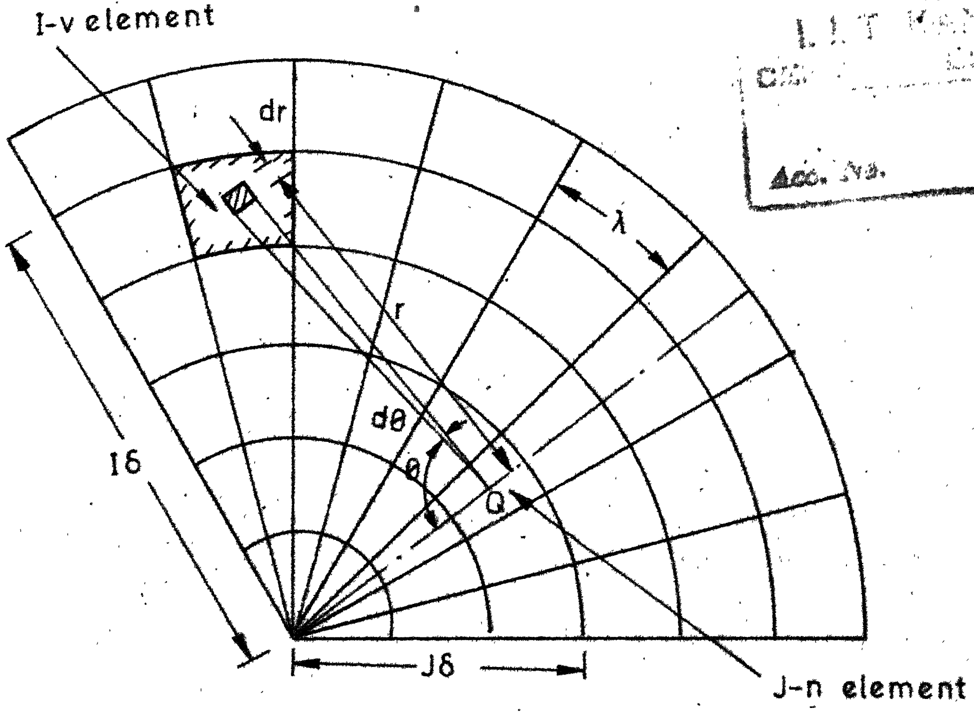

FIG. 2·3 GRAPHICAL REPRESENTATION OF THE METHOD FOR DETERMINATION OF γ(I,J,K)

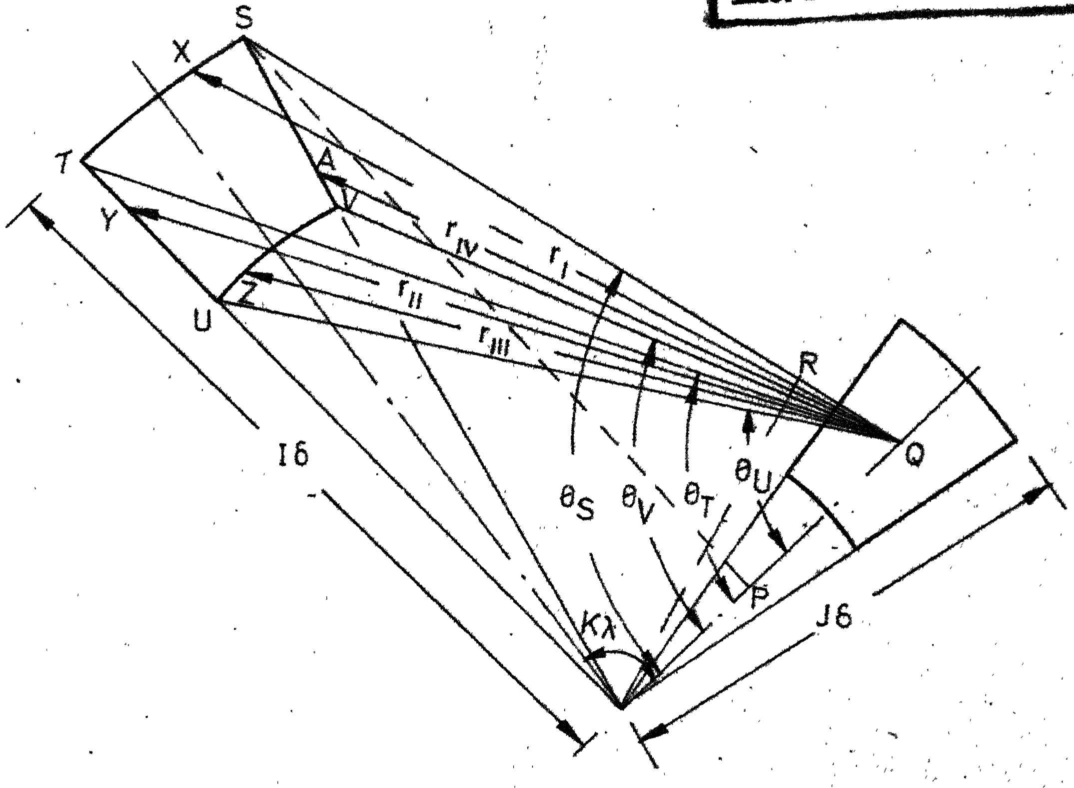

FIG. 2·4 DETERMINATION OF THE RADII AND THE ANGLE

CHAPTER III

RESULTS AND DISCUSSION

3.1 General Discussion

In the generalised nondimensional equation (2.36) terms containing properties of subgrade are $\bar{D}$ and $\bar{q}_{I-V}$ and therefore various kinds of settlement characteristics can be accommodated.

For solving the present problem the contact area of the subgrade and the plate has been divided into a number of elements by radial lines and concentric circles. The pressure intensity within one particular element has been assumed to remain constant. So it is obvious that the accuracy of the method will depend upon the fineness of the grid arrangement. The points at which the finite difference equations have been written are taken as the central points of the elements and not the intersection of the two sets of grid lines, as is conventionally done. The reason being that if there is a concentrated load at such a grid point it can be assumed with reasonable accuracy that the load is uniformly distributed over the whole element. But if the grid points were taken as the intersection, this could not have been done.

It was seen that the deflection co-efficients $\gamma(I,J,K)$ involve elliptic integrals. In the present analysis these integrals have been evaluated by numerical integration using Simpson's Rule. Another method of approximately evaluating these integrals, as used by Ghosh and Chatterjee[6], is to assume that the approximate values of the integrals are m'n' and m"n" as shown in Fig. 3.1. The values of $\gamma(I,J,K)$ calculated by both the methods are quite near except for the elements in the central zone. The reason probably is that the assumptions of the latter method are not acceptable there. The deflection as obtained by using the present method of calculating $\gamma(I,J,K)$ by numerical integration are in better agreement with the experimental results.

The present method is perfectly general in the sense that once the results for the present problem of a single concentrated load at various radial positions are known the solution for any particular loading condition can be very easily obtained by proper superposition. To demonstrate how this can be done a few examples for various types of loadings have been solved in the section 3.3.

As the present analysis is non-dimensional it can be used for any plate dimension and any plate or subgrade material.

Though there may be some inaccuracy in the deflection pattern for a single concentrated load (specially when the load is near the central zone), the results are found to be sufficiently consistent and accurate when there is a number of concentrated loads or when the load is distributed over a considerable portion of the plate.

3.2 Results

In the present work the non-dimensional deflection $\bar{w}$, moments $\bar{M}_\rho$ and $\bar{M}_\theta$ have been calculated for 25 different combinations of $\bar{D}$ and μ (five different values of $\bar{D}$ and five different values of μ). This covers quite a wide range of situations that may arise in practice.

A sample set of results for $\bar{D}$ = .01 and μ = .2 are given in Tables 1 through 3. The deflection contours for this case are shown in Fig. 3.2 through Fig. 3.7.

But the main object of the present work is to provide the designers with some simple and ready-made method of solution for circular plates on elastic foundation. This is done by presenting the final results in the form of polynomial equation in terms of the independent variables like, $\bar{D}$, μ, the co-ordinates of a particular point and also the load position. One polynomial equation is given for each of the thirteen sectors. The method used to determine the polynomials is given in Appendix B. The co-efficients of the polynomial equations are given in Tables 14 A through M The method of determining the deflections for various cases of loadings, by using these co-efficients, has been discussed in section 3.4.

3.3 Examples

Example 1: In this case the deflections for two equally spaced concentrated loads have been determined. The loads are in

sectors 1 and 13. From symmetry it is seen that it is sufficient to calculate the deflections only for the elements in sectors 1 through 7. To determine the deflection of any particular element we have to add algebrically the deflections of that element due to the two loads. The results are shown in Table 4.

Example II : In this example the deflections for three equally spaced loads have been obtained. The loads are assumed to be at sectors 1, 9 and 17. From symmetry of the problem it is seen that it is sufficient to calculate the deflections of the elements in sectors 1 through 5. Here to get the deflection, the deflections due to the three loads are to be added algebrically. The results are shown in Table 5.

Example III : In this example the deflections due to four equally spaced loads have been calculated. The loads are assumed to be in sectors 1,7,13 and 19. From symmetry, it is sufficients to calculate deflections of the elements in sectors 1 through 4. Here the deflections due to the four different loads are to be added. The results are shown in Table 6.

Example IV : In this example the deflections due to six equally spaced loads have been calculated. The loads are at sectors 1,5,9,13,17 and 21. Here it is sufficient to calculate the deflections for elements in sectors 1 through 3. in this case the deflections due to the six loads are to be added. The results are shown in Table 7. The deflection contours when the loads are on the fifth pitch circle are shown in Fig. 3.8.

Example V : In this example the deflections due to eight equally spaced concentrated loads have been calculated. The loads are at sectors 1,4,7,10,13,16,19 and 22. Here it is sufficient to calculate the deflections of the 12 elements in the first two sectors. In this case the deflections due to the eight different loads are to be added. Results are shown in Table 8.

Example VI : In this example the deflections due to twelve equally spaced concentrated loads have been calculated. The loads are assumed to be at sectors 1,3,5,7,9,11,13,15,17,19,21 and 23. Here also it is sufficient to calculate the deflections of the 12 elements in the first two sectors. In this case the deflections due to the twelve loads are to be added. The results are shown in Table 9.

Example VII : In this example the deflections due to a ring load have been calculated. In this case from the symmetry of the problem it is seen that the deflection is independent of θ and hence it is sufficient to calculate the deflections for the six elements in sector 1. Here the deflections due to the loads in the 24 elements of the ring are to be added algebrically. The results are shown in Table 10.

Example VIII : In this example the deflections due to a diametral line load have been calculated. The load line is assumed to be the centre line of sector 1 and sector 13. Here from symmetry of the problem it is seen that it is sufficient to calculate the deflections of the elements in sectors 1 through 13. Here the

deflections due the loads on the 12 elements of the load line has to be added. The results are shown in Table 12. The deflection contour has been shown in Fig. 3.10.

Example IX : In this example deflections for a radial line load have been calculated. The load line is assumed to be the central line of sector 1. Here from symmetry it is necessary to calculate the deflections of the elements in sectors 1 through 13. In this case the deflections due to the six load on six elements of the load line are to be added. The results are shown in Table 11. The deflection contour has been shown in Fig. 3.9.

Example X : In this example deflections for a uniformly distributed load over the whole plate has been calculated. Here it has to be noted that the loads on the various elements are not equal because in this case the load is directly proportional to the area of the particular element. It has been assumed that the load on the elements (1,v) are unity. The loads at the other elements have been calculated accordingly. From symmetry of the problem it is seen that as in Example VII here also the deflections will be independent of θ and hence it is sufficient to calculate the deflections only for the six elements in the first sector. In this case the deflections due to the loads on each of the 144 elements of the plate are to be added. The results are shown in Table 13, The corresponding pressure is found to $(2/\lambda\delta^2)$.

3.4 Discussion on Results

The results obtained by the present method have been compared with some experimental results for the case of six concentrated loads, given by Chatterjee and Ghosh[6]. The aggrement of the results are quite good. The maximum variation is about 20% very near the centre of the plate where the deflection is not very important. The variation in the maximum deflection is only about 1.5%. The deflection obtained by the present theoretical method is on the safer side. What is more important is that the nature of variation of the deflection as obtained by this method is almost the same as in experimental case. This has been shown in Fig. 3.11.

From the results obtained it is seen that the deflections are the maximum under the load points in the case of single concentrated load. This is quite reasonable. One more point to be noted is that though the deflection pattern as a whole depends to some extent on the value of Poisson's Ratio, μ, of the plate, the maximum deflection is almost independent of μ. The variation being of only about 5% when μ is changed from .1 to .4.

From the results obtained it has been found that though at certain points far away from the load point deflections may increas with the increase in $\bar{D}$, due to some change in the deflection pattern, the maximum deflection decreases substantially with the increase in $\bar{D}$. This is what one expects.

From the deflection contours it is seen that away from the load point the contours become almost circles, with the centre at the load point, which is reasonable. Near the load point the eccentricity of the load plays an important role and thus the contours are no longer circular in nature.

From the results it has been found that as the load point is moved away from the centre of the plate the maximum deflection under the load at first decreases and then increases. It has been found that this deflection reaches a minimum when the load is at the fifth radial position for small values of $\bar{D}$ and at fourth radial position when $\bar{D}$ is larger. Same are the positions in the case of $\bar{M}_\rho$ and $\bar{M}_\theta$.

To use the coefficients of the polynomial functions one has to keep in mind that the co-efficients are numbered 1 to 750. To get the deflections for a particular case, first $\bar{D}$ has to be calculated. Then for the proper μ and load position the deflections for the various elements in each of the sectors can be calculated by using the Computer Program No.2 in Appendix C.

For all the results $\bar{q}_{I,v}$ is assumed to be unity. To get the deflections and moments for a particular load the quantities calculated will have to be multiplied by the proper $\bar{q}_{I,v}$, calculated from equation (2.35) for the particular load. This is possible because $\bar{q}_{I,v}$ appeares on the right hand side of the generalised equation (2.36) for each and every I and v.

TABLE 1 - NONDIMENSIONAL DEFLECTIONS
D=.01 AND μ=.2

A. FOR LOAD AT RADIAL POSITION NO=1

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1104E 01	0.3930E 00	0.1675E 00	0.1006E 00	0.7230E-01	0.5642E-01
2	0.1041E 01	0.3766E 00	0.1632E 00	0.9904E-01	0.7152E-01	0.5593E-01
3	0.8893E 00	0.3339E 00	0.1517E 00	0.9479E-01	0.6934E-01	0.5453E-01
4	0.6904E 00	0.2763E 00	0.1357E 00	0.8868E-01	0.6612E-01	0.5244E-01
5	0.4864E 00	0.2160E 00	0.1184E 00	0.8176E-01	0.6239E-01	0.5001E-01
6	0.3129E 00	0.1634E 00	0.1027E 00	0.7510E-01	0.5868E-01	0.4756E-01
7	0.1939E 00	0.1253E 00	0.9054E-01	0.6950E-01	0.5545E-01	0.4546E-01
8	0.1386E 00	0.1049E 00	0.8275E-01	0.6538E-01	0.5291E-01	0.4380E-01
9	0.1418E 00	0.1007E 00	0.7925E-01	0.6279E-01	0.5114E-01	0.4263E-01
10	0.1856E 00	0.1084E 00	0.7905E-01	0.6152E-01	0.5006E-01	0.4191E-01
11	0.2450E 00	0.1212E 00	0.8065E-01	0.6112E-01	0.4950E-01	0.4152E-01
12	0.2941E 00	0.1323E 00	0.8232E-01	0.6112E-01	0.4927E-01	0.4135E-01
13	0.3131E 00	0.1367E 00	0.8317E-01	0.6117E-01	0.4921E-01	0.4131E-01

B. FOR LOAD AT RADIAL POSITION NO=2

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2970E 00	0.8090E 00	0.3054E 00	0.1443E 00	0.9086E-01	0.6652E-01
2	0.2901E 00	0.6064E 00	0.2593E 00	0.1345E 00	0.8791E-01	0.6526E-01
3	0.2710E 00	0.3957E 00	0.1937E 00	0.1162E 00	0.8101E-01	0.6188E-01
4	0.2437E 00	0.2588E 00	0.1415E 00	0.9904E-01	0.7274E-01	0.5732E-01
5	0.2134E 00	0.1823E 00	0.1193E 00	0.8470E-01	0.6484E-01	0.5229E-01
6	0.1849E 00	0.1412E 00	0.1005E 00	0.7508E-01	0.5922E-01	0.4754E-01
7	0.1623E 00	0.1184E 00	0.8718E-01	0.6784E-01	0.5470E-01	0.4491E-01
8	0.1474E 00	0.1052E 00	0.7932E-01	0.6237E-01	0.5099E-01	0.4261E-01
9	0.1402E 00	0.9746E-01	0.7354E-01	0.5834E-01	0.4812E-01	0.4065E-01
10	0.1392E 00	0.9329E-01	0.6976E-01	0.5551E-01	0.4601E-01	0.3913E-01
11	0.1417E 00	0.9134E-01	0.6745E-01	0.5366E-01	0.4460E-01	0.3806E-01
12	0.1446E 00	0.9062E-01	0.6623E-01	0.5262E-01	0.4379E-01	0.3744E-01
13	0.1459E 00	0.9046E-01	0.6585E-01	0.5229E-01	0.4353E-01	0.3723E-01

C. FOR LOAD AT RADIAL POSITION NO=3

CTOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.1340E 00	0.2943E 00	0.7968E 00	0.3072E 00	0.1433E 00	0.8851E-01
2	0.1328E 00	0.2541E 00	0.4373E 00	0.2229E 00	0.1253E 00	0.8367E-01
3	0.1292E 00	0.1974E 00	0.2283E 00	0.1457E 00	0.9911E-01	0.7341E-01
4	0.1237E 00	0.1524E 00	0.1418E 00	0.1056E 00	0.7781E-01	0.6250E-01
5	0.1171E 00	0.1220E 00	0.1046E 00	0.8337E-01	0.6604E-01	0.5303E-01
6	0.1103E 00	0.1023E 00	0.8539E-01	0.6974E-01	0.5734E-01	0.4760E-01
7	0.1040E 00	0.8939E-01	0.7362E-01	0.6068E-01	0.5079E-01	0.4309E-01
8	0.9884E-01	0.8069E-01	0.6576E-01	0.5444E-01	0.4601E-01	0.3950E-01
9	0.9502E-01	0.7474E-01	0.6037E-01	0.5009E-01	0.4258E-01	0.3682E-01
10	0.9250E-01	0.7072E-01	0.5670E-01	0.4710E-01	0.4018E-01	0.3492E-01
11	0.9104E-01	0.6816E-01	0.5432E-01	0.4515E-01	0.3861E-01	0.3364E-01
12	0.9033E-01	0.6673E-01	0.5299E-01	0.4404E-01	0.3771E-01	0.3291E-01
13	0.9012E-01	0.6628E-01	0.5256E-01	0.4368E-01	0.3742E-01	0.3267E-01

D. FOR LOAD AT RADIAL POSITION NO=4

CTOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.8680E-01	0.1382E 00	0.2993E 00	0.7602E 00	0.3023E 00	0.1378E 00
2	0.8634E-01	0.1301E 0	0.22 1E 00	0.3255E 00	0.1916E 00	0.1146E 00
3	0.8496E-01	0.1148E 00	0.1485E 00	0.1554E 00	0.1143E 00	0.8506E-01
4	0.8282E-01	0.9945E-01	0.1072E 00	0.9907E-01	0.8147E-01	0.6438E-01
5	0.8015E-01	0.8653E-01	0.8409E-01	0.7486E-01	0.6397E-01	0.5367E-01
6	0.7724E-01	0.7644E-01	0.7004E-01	0.6142E-01	0.5310E-01	0.4576E-01
7	0.7439E-01	0.6881E-01	0.6085E-01	0.5289E-01	0.4595E-01	0.4009E-01
8	0.7182E-01	0.6313E-01	0.5455E-01	0.4715E-01	0.4108E-01	0.3609E-01
9	0.6969E-01	0.5898E-01	0.5017E-01	0.4320E-01	0.3771E-01	0.3327E-01
10	0.6806E-01	0.5604E-01	0.4716E-01	0.4050E-01	0.3539E-01	0.3131E-01
11	0.6693E-01	0.5408E-01	0.4519E-01	0.3875E-01	0.3388E-01	0.3002E-01
12	0.6628E-01	0.5296E-01	0.4407E-01	0.3775E-01	0.3302E-01	0.2929E-01
13	0.6607E-01	0.5260E-01	0.4371E-01	0.3743E-01	0.3275E-01	0.2906E-01

E. FOR LOAD AT RADIAL POSITION NO=5

CTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.6525E-01	0.8809E-01	0.1396E 00	0.2964E 00	0.7114E 00	0.2878E 00
2	0.6498E-01	0.8571E-01	0.1235E 00	0.1905E 00	0.2551E 00	0.1625E 00
3	0.6417E-01	0.7999E-01	0.1001E 00	0.1179E 00	0.1178E 00	0.8804E-01
4	0.6293E-01	0.7301E-01	0.8098E-01	0.8275E-01	0.7682E-01	0.6544E-01
5	0.6137E-01	0.6617E-01	0.6730E-01	0.6423E-01	0.5840E-01	0.5150E-01
6	0.5965E-01	0.6020E-01	0.5771E-01	0.5317E-01	0.4789E-01	0.4263E-01
7	0.5794E-01	0.5529E-01	0.5094E-01	0.4599E-01	0.4120E-01	0.3682E-01
8	0.5636E-01	0.5142E-01	0.4611E-01	0.4111E-01	0.3671E-01	0.3289E-01
9	0.5502E-01	0.4848E-01	0.4266E-01	0.3773E-01	0.3362E-01	0.3016E-01
10	0.5396E-01	0.4633E-01	0.4025E-01	0.3541E-01	0.3152E-01	0.2830E-01
11	0.5321E-01	0.4488E-01	0.3866E-01	0.3390E-01	0.3015E-01	0.2708E-01
12	0.5277E-01	0.4404E-01	0.3775E-01	0.3304E-01	0.2937E-01	0.2639E-01
13	0.5262E-01	0.4376E-01	0.3736E-01	0.3276E-01	0.2912E-01	0.2617E-01

F. FOR LOAD AT RADIAL POSITION NO=6

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.5210E-01	0.6505E-01	0.8694E-01	0.1350E 00	0.2827E 00	0.7244E 00
2	0.5192E-01	0.6397E-01	0.8262E-01	0.1136E 00	0.1625E 00	0.2105E 00
3	0.5139E-01	0.6107E-01	0.7317E-01	0.8626E-01	0.9538E-01	0.9373E-01
4	0.5057E-01	0.5717E-01	0.6323E-01	0.6690E-01	0.6654E-01	0.6226E-01
5	0.4955E-01	0.5303E-01	0.5480E-01	0.5426E-01	0.5159E-01	0.4759E-01
6	0.4842E-01	0.4917E-01	0.4823E-01	0.4587E-01	0.4265E-01	0.3908E-01
7	0.4728E-01	0.4583E-01	0.4328E-01	0.4013E-01	0.3684E-01	0.3363E-01
8	0.4623E-01	0.4309E-01	0.3959E-01	0.3612E-01	0.3290E-01	0.2997E-01
9	0.4531E-01	0.4095E-01	0.3689E-01	0.3330E-01	0.3017E-01	0.2745E-01
10	0.4458E-01	0.3935E-01	0.3497E-01	0.3134E-01	0.2831E-01	0.2573E-01
11	0.4405E-01	0.3824E-01	0.3368E-01	0.3005E-01	0.2709E-01	0.2461E-01
12	0.4374E-01	0.3760E-01	0.3295E-01	0.2931E-01	0.2640E-01	0.2398E-01
13	0.4363E-01	0.3739E-01	0.3271E-01	0.2908E-01	0.2617E-01	0.2377E-01

TABLE 2 .. NONDIMENSIONAL MOMENTS $\bar{M}_\rho$
D=.01 AND μ=.2

A. FOR LOAD AT RADIAL POSITION NO=1

TOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.1870E 00	-0.3203E-01	0.1623E-03	0.4479E-04	-0.3843E-04	-0.3741E-03
2	-0.6001E-01	0.3190E-01	-0.1039E-01	0.2196E-04	-0.4044E-04	-0.1342E-03
3	-0.1995E-01	-0.4914E-02	0.9487E-02	-0.4837E-02	0.3275E-05	-0.5439E-04
4	-0.5630E-02	-0.1835E-02	0.4169E-04	0.1956E-02	-0.1791E-02	-0.7145E-05
5	-0.4152E-02	-0.4495E-03	-0.1305E-03	-0.1822E-03	0.1476E-02	-0.1344E-02
6	-0.8156E-02	-0.1501E-03	-0.5261E-04	-0.5231E-04	-0.1404E-02	0.3891E-02
7	-0.1186E 00	0.2499E-04	-0.3100E-04	-0.4779E-04	-0.3403E-03	-0.1624E-02
8	0.2141E 00	-0.1805E-01	0.3070E-04	-0.3223E-04	-0.1176E-03	-0.4154E-03
9	-0.5399E-01	0.2368E-01	-0.7674E-02	0.1114E-04	-0.5097E-04	-0.1341E-03
.0	-0.1827E-01	-0.2882E-02	0.5214E-02	-0.3030E-02	-0.3849E-05	-0.5477E-04
.1	-0.5269E-02	-0.1167E-02	0.1081E-03	0.1158E-02	-0.1322E-02	0.8300E-04
.2	-0.4170E-02	-0.3068E-03	-0.4161E-04	-0.8378E-03	0.2671E-02	-0.1824E-02
.3	-0.1214E-01	-0.5856E-03	-0.2513E-03	-0.2944E-03	-0.1872E-02	0.4978E-02

B. FOR LOAD AT RADIAL POSITION NO=2

TOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	-0.1146E 00	-0.8370E-02	0.2408E-03	0.4170E-04	-0.1194E-04	-0.1123E-03
2	0.1308E 00	-0.1264E-02	-0.3112E-02	0.1230E-0	-0.1679E-04	-0.6935E-04
3	-0.3969E-01	0.7024E-02	0.1035E-02	-0.2114E-02	0.2730E-04	-0.3645E-04
4	-0.1408E-01	-0.1032E-02	0.2475E-03	0.1526E-02	-0.1462E-02	-0.1770E-05
5	-0.7825E-02	-0.3453E-03	-0.9338E-04	-0.2648E-03	0.1529E-02	-0.1221E-02
6	-0.2226E-02	-0.1124E-03	-0.6647E-03	-0.9261E-04	-0.3857E-03	0.1713E-02
7	-0.3146E-01	0.1158E-03	-0.3691E-04	-0.4592E-04	-0.1388E-03	-0.4063E-03
8	-0.3503E-02	-0.5210E-02	0.5421E-04	-0.2201E-04	-0.6471E-04	-0.1546E-03
9	0.8591E-01	0.1183E-02	-0.[illegible]743E-02	0.1467E-0	-0.2921E-04	-0.7429E-04
0	-0.2502E-01	0.2410E-02	0.1726E-02	-0.1795E-02	0.1056E-04	-0.4195E-04
1	-0.1066E-01	-0.5805E-03	-0.1486E-03	0.1600E-02	-0.1325E-02	-0.1003E-04
2	-0.8697E-02	-0.2121E-03	-0.1062E-03	-0.3429E-03	0.1650E-02	-0.1227E-02
3	-0.7231E-02	-0.6373E-03	-0.2590E-03	-0.2258E-03	-0.5202E-03	0.1877E-02

C. FOR LOAD AT RADIAL POSITION NO=3

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	-0.3596E-01	-0.3154E-02	0.3643E-03	0.2611E-04	-0.2716E-04	-0.6141E-04
2	-0.3661E-01	-0.4611E-03	-0.1219E-02	0.3020E-04	-0.2946E-04	-0.5186E-04
3	0.1276E 00	-0.4254E-02	0.3617E-03	-0.9679E-03	0.9135E-05	-0.3401E-04
4	-0.3811E-01	0.1869E-02	-0.7292E-03	0.7476E-03	-0.8121E-03	-0.9830E-05
5	-0.1365E-01	-0.6218E-05	-0.2185E-03	-0.2029E-03	0.8410E-03	-0.7376E-03
6	-0.1497E-02	-0.4098E-05	-0.6791E-03	-0.1130E-03	-0.1642E-03	0.8810E-03
7	-0.1630E-01	0.3620E-03	-0.3518E-04	-0.5615E-04	-0.8856E-04	-0.1558E-03
8	-0.2239E-02	-0.2149E-02	0.7037E-04	-0.1978E-04	-0.5408E-04	-0.8475E-04
9	-0.4774E-02	0.2837E-03	-0.1226E-02	0.3577E-04	-0.3378E-04	-0.5275E-04
0	0.5087E-01	-0.1700E-02	0.7408E-03	-0.9121E-03	-0.4319E-05	-0.3556E-04
	-0.1725E-01	-0.3591E-05	-0.3016E-03	0.8572E-03	-0.7843E-03	-0.1394E-04
2	-0.7649E-02	-0.7736E-04	-0.1510E-03	-0.1748E-03	0.8868E-03	-0.7295E-03
3	-0.1005E-01	-0.6894E-03	-0.1822E-03	-0.1608E-03	-0.2147E-03	0.9456E003

D. FOR LOAD AT RADIAL POSITION NO=4

OR	RADIAL POSITIONS 1	2	3	4	5	6
	-0.1166E-01	-0.1866E-02	0.5379E-03	-0.1341E-04	-0.4079E-04	-0.4611E-04
	-0.1259E-01	0.1319E-03	-0.6614E-03	0.6181E-04	-0.4139E-04	-0.4354E-04
	-0.3299E-01	-0.1402E-02	0.2435E-03	-0.4975E-03	-0.1043E-04	-0.3190E-04
	0.1189E 00	-0.4701E-02	-0.4274E-03	0.4284E-03	-0.4901E-03	-0.1460E-04
	-0.3111E-01	0.1220E-04	-0.4943E-03	-0.1517E-03	0.5134E-03	-0.4792E-03
	-0.4123E-02	0.4755E-04	-0.2251E-03	-0.1169E-03	-0.1023E-03	0.5492E-03
	-0.2361E-01	0.9647E-03	-0.8994E-04	-0.8209E-04	-0.6922E-04	-0.8751E-04
	0.3300E-02	-0.1281E-02	0.1257E-03	-0.4918E-04	-0.4936E-04	-0.5826E-04
	-0.6207E-02	0.2090E-03	-0.5869E-03	0.5090E-05	-0.3531E-04	-0.4202E-04
	-0.4671E-02	-0.7740E-03	0.4040E-03	-0.5169E-03	-0.1347E-04	-0.3112E004
	0.3076E-01	-0.1503E-02	-0.2211E-03	0.5081E-03	-0.4954E-03	-0.1618E-04
	-0.5104E-02	-0.4311E-03	-0.1965E-03	-0.1181E-03	0.5497E-03	-0.4818E-03
	-0.1736E-01	-0.5519E-03	-0.2015E-03	-0.1229E-03	-0.1247E-03	0.5936E-03

E. FOR LOAD AT RADIAL POSITION NO=5

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	-0.5843E-02	-0.9975E-03	0.5653E-03	-0.7569E-04	-0.4482E-04	-0.3769E-04
2	-0.4395E-02	0.2380E-04	-0.2564E-03	0.1484E-04	-0.4543E-04	-0.3751E-04
3	-0.1198E-01	-0.4134E-03	0.1206E-03	-0.2667E-03	-0.2250E-04	-0.2957E-04
4	-0.2640E-01	-0.1440E-02	-0.2230E-03	0.2752E-03	-0.3198E-03	-0.1738E004
5	0.1100E 00	-0.4767E-02	-0.3412E-03	-0.1098E-03	0.3503E-03	-0.3373E-03
6	-0.1323E-01	-0.6306E-03	-0.3632E-03	-0.1024E-03	-0.7344E-04	0.3845E-03
7	-0.3971E-01	0.1280E-02	-0.1505E-03	-0.8668E-03	-0.5654E-04	-0.5905E-04
8	0.2483E-02	-0.1279E-02	0.2278E-03	-0.6534E-04	-0.4462E-04	-0.4420E-04
9	-0.6723E-02	0.1725E-03	-0.2589E-03	-0.2172E-03	-0.3509E-04	-0.3447E-04
0	-0.4187E-02	-0.3014E-03	0.2350E-03	-0.3150E-03	-0.1952E-04	-0.2733E-04
1	0.2002E-02	-0.7201E-03	-0.1454E-03	0.3374E-03	-0.3386E-03	-0.1688E004
2	0.2175E-01	-0.1242E-02	-0.1654E-03	-0.8635E-04	0.3809E-03	-0.3459E-03
3	-0.1981E-01	-0.7012E-03	-0.1960E-03	-0.9614E-04	-0.8567E-04	0.4191E-03

F. FOR LOAD AT RADIAL POSITION NO=6

OR	RADIAL POSITIONS 1	2	3	4	5	6
	-0.6852E-02	0.9718E-02	-0.1693E-02	-0.1066E-03	-0.4272E-04	-0.3107E-04
	-0.1659E-02	-0.3085E-02	0.2334E-03	-0.1038E-03	-0.4490E-04	-0.3229E-04
	-0.2957E-02	-0.1500E-03	-0.8323E-05	-0.1268E-03	-0.3277E-04	-0.2691E-04
	-0.1047E-01	-0.3751E-03	-0.1256E-03	0.1858E-03	-0.2171E-03	-0.1881E-04
	-0.3021E-01	-0.1446E-02	-0.1979E-03	-0.7917E-04	0.2541E-03	-0.2485E-03
	0.1632E-01	-0.5293E-02	-0.2706E-03	-0.8127E-04	-0.5490E-04	0.2850E-03
	0.1873E 00	-0.9279E-02	-0.2792E-03	-0.7767E-04	-0.4616E-04	-0.4283E-04
	-0.1339E 00	0.1335E-02	-0.3045E-03	-0.6821E-04	-0.3916E-04	-0.3494E-04
	-0.2359E-02	-0.6561E-03	-0.3076E-04	-0.5204E-04	-0.3320E-04	-0.2891E-04
	-0.1553E-02	-0.1372E-03	0.1285E-03	-0.1946E-03	-0.2336E-04	-0.2426E-04
	-0.1274E-02	-0.2892E-03	-0.9651E-04	0.2385E-03	-0.2422E-03	-0.1679E-04
	0.2032E-02	-0.6409E-03	-0.1191E-03	-0.6440E-04	0.2800E-03	-0.2599E-03
	0.1420E-01	-0.1132E-02	-0.1552E-03	-0.7521E-04	-0.6230E-04	0.3122E-03

TABLE 3 - NONDIMENSIONAL MOMENTS $\bar{M}_\theta$: D=.01 AND μ=.2

A. FOR LOAD AT RADIAL POSITION NO=1

CTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.8338E 00	-0.1086E 00	0.5785E-03	0.2457E-03	0.1430E-03	0.2916E-04
2	-0.2916E 00	0.9487E-01	-0.1077E-01	-0.1908E-04	-0.4616E-04	-0.8073E-04
3	-0.9506E-01	-0.2524E-01	0.1854E-01	-0.2278E-02	-0.1539E-04	-0.4132E-04
4	-0.2269E-01	-0.8538E-02	-0.3944E-02	0.3218E-02	-0.9962E-03	-0.1523E-04
5	-0.5075E-02	-0.2194E-02	-0.1452E-02	-0.4539E-03	0.1416E-02	-0.1194E-02
6	0.7108E-02	-0.7738E-03	-0.4312E-03	-0.1940E-03	-0.5812E-03	0.2387E-02
7	-0.5921E 00	-0.1178E-03	-0.1914E-03	-0.1125E-03	-0.1579E-03	-0.9149E-03
8	0.9753E 00	-0.4175E-01	-0.3555E-04	-0.7031E-04	-0.8358E-04	-0.2447E-03
9	-0.2695E 00	0.7204E-01	-0.6717E-02	-0.1946E-04	-0.4867E-04	-0.9141E-04
10	-0.8892E-01	-0.1808E-01	0.1101E-01	-0.1522E-02	-0.1726E-04	-0.4397E-04
11	-0.2130E-01	-0.6267E-02	-0.1976E-02	0.1971E-02	-0.1264E-02	0.1007E-04
12	-0.4596E-02	-0.1683E-02	-0.7796E-03	-0.4148E-03	0.2190E-02	-0.1480E-02
13	-0.9941E-02	-0.2987E-02	-0.1320E-02	-0.6101E-03	-0.1669E-02	0.3471E-02

B. FOR LOAD AT RADIAL POSITION NO=2

CTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	-0.5964E 00	-0.2911E-01	0.6829E-03	0.2685E-03	0.1438E-03	0.8484E-04
2	0.5934E 00	0.8540E-02	-0.4354E-02	-0.1337E-04	-0.3261E-04	-0.4916E-04
3	-0.2023E 00	0.2204E-01	0.5424E-02	-0.1759E-02	-0.6564E-05	-0.2816E-04
4	-0.6250E-01	-0.8078E-02	0.8247E-03	0.2451E-02	-0.9487E-03	-0.9330E-05
5	-0.1316E-01	-0.2794E-02	-0.6594E-03	-0.2346E-03	0.1424E-02	-0.6915E-03
6	0.2958E-03	-0.1080E-02	-0.3568E-03	-0.1558E-03	-0.2647E-03	0.1139E-02
7	-0.1565E 00	-0.1162E-03	-0.1826E-03	-0.1000E-03	-0.1131E-03	-0.2670E-03
8	-0.4006E-01	-0.1383E-01	-0.1408E-04	-0.5100E-04	-0.6099E-04	-0.1057E-03
9	0.3874E 00	0.1354E-01	-0.3693E-02	-0.1161E-04	-0.3420E-04	-0.5223E-04
10	-0.1307E 00	0.8526E-02	0.5002E-02	-0.1550E-02	-0.9144E-05	-0.3022E-04
11	-0.4444E-01	-0.3925E-02	-0.9483E-04	0.2231E-02	-0.9305E-03	-0.1173E-04
12	-0.8336E-02	-0.1524E-02	-0.3755E-03	-0.3083E-03	0.1458E-02	-0.7084E-03
13	-0.2467E-01	-0.3433E-02	-0.1204E-02	-0.6620E-03	-0.8088E-03	0.1475E-02

C. FOR LOAD AT RADIAL POSITION NO=3

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	-0.1865E 00	-0.1076E-01	0.7826E-03	0.2390E-03	0.1119E-03	0.6589E-04
2	-0.1991E 00	0.1634E-02	-0.2042E-02	0.6501E-05	-0.1864E-04	-0.2892E-04
3	0.5816E 00	0.3646E-04	0.1858E-02	-0.9552E-03	-0.8873E-06	-0.1836E-04
4	-0.1881E 00	0.8032E-02	0.5926E-03	0.1195E-02	-0.5624E-03	-0.6429E-05
5	-0.6282E-01	-0.2119E-02	0.1502E-03	-0.1418E-03	0.8010E-03	-0.4012E-03
6	-0.4850E-02	-0.1285E-02	-0.5204E-04	-0.4312E-04	-0.9230E-04	0.6066E-03
7	-0.8002E-01	-0.3119E-04	-0.7941E-04	-0.3833E-04	-0.5398E-04	-0.9899E-04
8	-0.1738E-01	-0.6449E-02	0.1059E-04	-0.2496E-04	-0.3374E-04	-0.5270E-04
9	-0.3545E-01	0.3658E-02	-0.1960E-02	0.3662E-05	-0.2106E-04	-0.3144E-04
10	0.2344E 00	0.3153E-02	0.2129E-02	-0.8954E-03	-0.4793E-05	-0.2037E-04
11	-0.6260E-01	0.1979E-02	0.2218E-03	0.1202E-02	-0.5512E-03	-0.8741E-05
12	-0.3108E-01	-0.4113E-03	-0.1061E-04	-0.8153E-04	0.8079E-03	-0.4013E003
13	-0.4812E-01	-0.3553E-02	-0.7148E-03	-0.3749E-03	-0.3705E-03	0.7965E-03

D. FOR LOAD AT RADIAL POSITION NO=4

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	-0.5921E-01	-0.5908E-02	0.9742E-03	0.1888E-03	0.8215E-04	0.4738E-04
2	-0.6296E-01	0.1272E-02	-0.1302E-02	0.2297E-04	-0.1014E-04	-0.1849E-04
3	-0.1725E 00	0.1805E-03	0.8528E-03	-0.5462E-03	0.1145E-05	-0.1260E-04
4	0.5392E 00	0.2884E-02	0.2547E-03	0.6428E-03	-0.3546E-03	-0.4851E-05
5	-0.1708E 00	0.3689E-02	0.2191E-03	0.1660E-04	0.4885E-03	-0.2629E-03
6	-0.2422E-01	-0.5274E-03	0.9503E-04	-0.1594E-05	-0.4009E-04	0.3821E-03
7	-0.1146E 00	0.4277E-03	0.3068E-04	-0.9154E-05	-0.2784E-04	-0.4971E-04
8	0.1720E-01	-0.4438E-02	0.5909E-04	-0.7840E-05	-0.1930E-04	-0.3115E-04
9	-0.2504E-01	0.1362E-02	-0.1080E-02	0.9609E-05	-0.1289E-04	-0.2100E-04
10	-0.3219E-02	0.8551E-03	0.1011E-02	-0.5449E-03	-0.2556E-05	-0.1449E-04
11	0.1421E 00	0.1485E-02	0.1492E-03	0.6986E-03	-0.3566E-03	-0.6981E-05
12	-0.3252E-01	0.8923E-03	0.7946E-04	-0.2216E-04	0.5038E-03	-0.2653E-03
13	-0.8970E-01	-0.2131E-02	-0.3750E-03	-0.2134E-03	-0.2037E-03	0.5163E-03

E. FOR LOAD AT RADIAL POSITION NO=5

TOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	-0.2561E-01	-0.2840E-02	0.9055E-03	0.1385E-03	0.6005E-04	0.3473E-04
2	-0.1511E-01	0.4694E-03	-0.7206E-03	0.2618E-04	-0.5397E-05	-0.1281E-04
3	-0.6033E-01	-0.9940E-04	0.3095E-03	-0.3263E-03	0.1721E-05	-0.9148E-05
4	-0.1497E 00	0.5925E-03	0.1186E-03	0.3799E-03	-0.2398E-03	-0.3881E-05
5	0.4915E 00	0.2222E-02	0.1461E-03	0.1431E-04	0.3278E-03	-0.1875E-03
6	-0.8500E-01	0.2436E-02	0.1176E-03	0.7986E-05	-0.2209E-04	0.2675E-03
7	-0.1948E 00	0.1243E-02	0.7462E-04	0.2420E-05	-0.1628E-04	-0.3027E-04
8	0.2191E-01	-0.4637E-02	0.8999E-04	0.1128E-05	-0.1189E-04	-0.2086E-04
9	-0.4678E-02	0.9758E-03	-0.5872E-03	0.1094E-04	-0.8399E-05	-0.1492E-04
0	-0.1506E-01	0.2754E-03	0.4972E-03	-0.3523E-03	-0.1611E-05	-0.1088E-04
1	0.2308E-02	0.6589E-03	0.8633E-04	0.4465E-03	-0.2493E-03	-0.5691E-05
2	0.9248E-01	0.8627E-03	0.7302E-04	-0.7896E-05	0.3468E-03	-0.1919E-03
3	-0.1078E 00	-0.5287E-03	-0.1837E-03	-0.1313E-03	-0.1298E-03	0.3699E-03

F. FOR LOAD AT RADIAL POSITION NO=6

TOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	-0.1641E-01	0.2858E-01	0.3511E-03	0.9594E-04	0.4418E-04	0.2611E-04
2	-0.4274E-02	-0.1453E-01	0.9340E-04	0.1664E-04	-0.2729E-05	-0.9279E-05
3	-0.1475E-01	-0.6099E-04	-0.1837E-03	-0.1840E-03	0.1280E-05	-0.6890E-05
4	-0.5783E-01	0.1257E-03	0.6292E-04	0.2291E-03	-0.1683E-03	-0.3328E-05
5	-0.1710E 00	0.6871E-03	0.8981E-04	0.9759E-05	0.2321E-03	-0.1397E-03
6	0.1915E-01	0.1756E-02	0.9364E-04	0.8861E-05	-0.1388E-04	0.1975E-03
7	0.8866E 00	0.1661E-02	0.7689E-04	0.6227E-05	-0.1047E-04	-0.2024E-04
8	-0.6354E 00	0.2676E-02	0.6378E-04	0.5041E-05	-0.7643E-05	-0.1486E-04
9	-0.1941E-02	-0.3015E-02	-0.2114E-03	0.9062E-05	-0.5656E-05	-0.1110E-04
0	-0.6471E-02	0.1156E-03	0.1888E-03	-0.2322E-03	-0.1126E-05	-0.8497E-05
1	-0.1007E-01	0.2971E-03	0.5121E-04	0.3002E-03	-0.1819E-03	-0.4733E-05
2	0.8928E-03	0.4884E-03	0.5371E-04	-0.3758E-05	0.2520E-03	-0.1452E-03
3	0.5649E-01	0.2555E-03	-0.8507E-04	-0.8614E-04	-0.8924E-04	0.2780E-03

TABLE 4 - EXAMPLE 1

A. FOR LOAD AT RADIAL POSITION NO=1

	RADIAL POSITIONS					
CTOR	1	2	3	4	5	6
1	0.1417E 01	0.5297E 00	0.2507E 00	0.1617E 00	0.1215E 00	0.9773E-01
2	0.1335E 01	0.5089E 00	0.2457E 00	0.1602E 00	0.1208E 00	0.9728E-01
3	0.1134E 01	0.4550E 00	0.2323E 00	0.1559E 00	0.1188E 00	0.9605E-01
4	0.8760E 00	0.3846E 00	0.2147E 00	0.1502E 00	0.1162E 00	0.9435E-01
5	0.6282E 00	0.3167E 00	0.1976E 00	0.1446E 00	0.1135E 00	0.9264E-01
6	0.4515E 00	0.2682E 00	0.1855E 00	0.1405E 00	0.1116E 00	0.9136E-01
7	0.3877E 00	0.2507E 00	0.1811E 00	0.1390E 00	0.1109E 00	0.9091E-01

B. FOR LOAD AT RADIAL POSITION NO=2

	RADIAL POSITIONS					
CTOR	1	2	3	4	5	6
1	0.4429E 00	0.8994E 00	0.3713E 00	0.1966E 00	0.1344E 00	0.1038E 00
2	0.4347E 00	0.6970E 00	0.3255E 00	0.1871E 00	0.1317E 00	0.1027E 00
3	0.4127E 00	0.4871E 00	0.2612E 00	0.1699E 00	0.1256E 00	0.9994E-01
4	0.3829E 00	0.3521E 00	0.2183E 00	0.1545E 00	0.1188E 00	0.9645E-01
5	0.3536E 00	0.2798E 00	0.1928E 00	0.1430E 00	0.1130E 00	0.9294E-01
6	0.3323E 00	0.2464E 00	0.1798E 00	0.1374E 00	0.1102E 00	0.9015E-01
7	0.3246E 00	0.2368E 00	0.1758E 00	0.1357E 00	0.1094E 00	0.8982E-01

C. FOR LOAD AT RADIAL POSITION NO=3

	RADIAL POSITIONS					
CTOR	1	2	3	4	5	6
1	0.2241E 00	0.3606E 00	0.8493E 00	0.3509E 00	0.1807E 00	0.1212E 00
2	0.2231E 00	0.3208E 00	0.4903E 00	0.2669E 00	0.1630E 00	0.1166E 00
3	0.2202E 00	0.2656E 00	0.2826E 00	0.1909E 00	0.1377E 00	0.1071E 00
4	0.2162E 00	0.2231E 00	0.1985E 00	0.1527E 00	0.1180E 00	0.9741E-01
5	0.2121E 00	0.1967E 00	0.1650E 00	0.1335E 00	0.1086E 00	0.8985E-01
6	0.2091E 00	0.1830E 00	0.1512E 00	0.1242E 00	0.1033E 00	0.8710E-01
7	0.2080E 00	0.1788E 00	0.1472E 00	0.1214E 00	0.1016E 00	0.8618E-01

D. FOR LOAD AT RADIAL POSITION NO=4

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1529E 00	0.1908E 00	0.3430E 00	0.7976E 00	0.3350E 00	0.1669E 00
2	0.1526E 00	0.1830E 00	0.2641E 00	0.3633E 00	0.2247E 00	0.1439E 00
3	0.1519E 00	0.1689E 00	0.1937E 00	0.1942E 00	0.1482E 00	0.1151E 00
4	0.1509E 00	0.1555E 00	0.1544E 00	0.1396E 00	0.1169E 00	0.9569E-01
5	0.1498E 00	0.1455E 00	0.1333E 00	0.1181E 00	0.1017E 00	0.8693E-01
6	0.1491E 00	0.1396E 00	0.1236E 00	0.1086E 00	0.9418E-01	0.8185E-01
7	0.1488E 00	0.1376E 00	0.1217E 00	0.1058E 00	0.9190E-01	0.8017E-01

E. FOR LOAD AT RADIAL POSITION NO=5

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1179E 00	0.1318E 00	0.1771E 00	0.3291E 00	0.7405E 00	0.3140E 00
2	0.1177E 00	0.1297E 00	0.1612E 00	0.2236E 00	0.2845E 00	0.1889E 00
3	0.1174E 00	0.1249E 00	0.1387E 00	0.1518E 00	0.1479E 00	0.1151E 00
4	0.1169E 00	0.1193E 00	0.1212E 00	0.1182E 00	0.1083E 00	0.9374E-01
5	0.1164E 00	0.1147E 00	0.1100E 00	0.1020E 00	0.9203E-01	0.8166E-01
6	0.1160E 00	0.1116E 00	0.1038E 00	0.9428E-01	0.8460E-01	0.7551E-01
7	0.1159E 00	0.1106E 00	0.1019E 00	0.9198E-01	0.8240E-01	0.7365E-01

F. FOR LOAD AT RADIAL POSITION NO=6

TOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.9573E-01	0.1024E 00	0.1196E 00	0.1641E 00	0.3089E 00	0.7481E 00
2	0.9566E-01	0.1016E 00	0.1156E 00	0.1429E 00	0.1889E 00	0.2345E 00
3	0.9544E-01	0.9932E-01	0.1069E 00	0.1163E 00	0.1225E 00	0.1183E 00
4	0.9515E-01	0.9652E-01	0.9820E-01	0.9824E-01	0.9484E-01	0.8799E-01
5	0.9486E-01	0.9398E-01	0.9169E-01	0.8755E-01	0.8176E-01	0.7504E-01
6	0.9465E-01	0.9227E-01	0.8783E-01	0.8199E-01	0.7554E-01	0.6905E-01
7	0.9457E-01	0.9166E-01	0.8656E-01	0.8027E-01	0.7368E-01	0.6726E-01

D. FOR LOAD AT RADIAL POSITION NO=4

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2262E 00	0.2562E 00	0.3996E 00	0.8466E 00	0.3776E 00	0.2044E 00
2	0.2262E 00	0.2493E 00	0.3218E 00	0.4132E 00	0.2681E 00	0.1820E 00
3	0.2263E 00	0.2377E 00	0.2545E 00	0.2471E 00	0.1942E 00	0.1552E 00
4	0.2263E 00	0.2289E 00	0.2214E 00	0.1982E 00	0.1676E 00	0.1394E 00
5	0.2264E 00	0.2257E 00	0.2119E 00	0.1872E 00	0.1607E 00	0.1364E 00

E. FOR LOAD AT RADIAL POSITION NO=5

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1753E 00	0.1850E 00	0.2249E 00	0.3718E 00	0.7786E 00	0.3481E 00
2	0.1753E 00	0.1835E 00	0.2098E 00	0.2671E 00	0.3233E 00	0.2237E 00
3	0.1753E 00	0.1802E 00	0.1897E 00	0.1978E 00	0.1891E 00	0.1519E 00
4	0.1753E 00	0.1772E 00	0.1764E 00	0.1690E 00	0.1541E 00	0.1345E 00
5	0.1754E 00	0.1761E 00	0.1721E 00	0.1612E 00	0.1459E 00	0.12[illegible]2E 00

F. FOR LOAD AT RADIAL POSITION NO=6

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1427E 00	0.1469E 00	0.1607E 00	0.2016E 00	0.3431E 00	0.7793E 00
2	0.1427E 00	0.1464E 00	0.1562E 00	0.1811E 00	0.2237E 00	0.2662E 00
3	0.1427E 00	0.1451E 00	0.1501E 00	0.1564E 00	0.1593E 00	0.1520E 00
4	0.1427E 00	0.1439E 00	0.1444E 00	0.1421E 00	0.1356E 00	0.1253E 00
5	0.1427E 00	0.1435E 00	0.1423E 00	0.1376E 00	0.1294E 00	0.1190E 00

TABLE 6 - EXAMPLE 3

A. FOR LOAD AT RADIAL POSITION NO=1

SECTOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.1804E 01	0.7804E 00	0.4318E 00	0.3008E 00	0.2324E 00	0.1886E 00
2	0.1787E 01	0.7772E 00	0.4311E 00	0.3006E 00	0.2324E 00	0.1886E 00
3	0.1763E 01	0.7718E 00	0.4300E 00	0.3005E 00	0.2324E 00	0.1887E 00
4	0.1752E 01	0.7693E 00	0.4295E 00	0.3004E 00	0.2324E 00	0.1887E 00

B. FOR LOAD AT RADIAL POSITION NO=2

SECTOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.7675E 00	0.1136E 01	0.5470E 00	0.3323E 00	0.2438E 00	0.1936E 00
2	0.7670E 00	0.9433E 00	0.5053E 00	0.3246E 00	0.2419E 00	0.1928E 00
3	0.7662E 00	0.7669E 00	0.4530E 00	0.3129E 00	0.2386E 00	0.1929E 00
4	0.7659E 00	0.7042E 00	0.4365E 00	0.3091E 00	0.2375E 00	0.1929E 00

C. FOR LOAD AT RADIAL POSITION NO=3

SECTOR	RADIAL POSITIONS					
	1	2	3	4	5	6
1	0.4321E 00	0.5394E 00	0.9966E 00	0.4723E 00	0.2823E 00	0.2074E 00
2	0.4322E 00	0.5038E 00	0.6415E 00	0.3911E 00	0.2663E 00	0.2037E 00
3	0.4323E 00	0.4623E 00	0.4476E 00	0.3243E 00	0.2463E 00	0.1969E 00
4	0.4324E 00	0.4462E 00	0.3971E 00	0.3053E 00	0.2360E 00	0.1948E 00

D. FOR LOAD AT RADIAL POSITION NO=4

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.3017E 00	0.3284E 00	0.4637E 00	0.9034E 00	0.4269E 00	0.2471E 00
2	0.3017E 00	0.3226E 00	0.3887E 00	0.4718E 00	0.3188E 00	0.2258E 00
3	0.3017E 00	0.3144E 00	0.3280E 00	0.3123E 00	0.2499E 00	0.2020E 00
4	0.3018E 00	0.3110E 00	0.3088E 00	0.2791E 00	0.2337E 00	0.1914E 00

E. FOR LOAD AT RADIAL POSITION NO=5

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2338E 00	0.2424E 00	0.2790E 00	0.4211E 00	0.8229E 00	0.3876E 00
2	0.2338E 00	0.2414E 00	0.2650E 00	0.3179E 00	0.3691E 00	0.2644E 00
3	0.2338E 00	0.2395E 00	0.2487E 00	0.2538E 00	0.2400E 00	0.1968E 00
4	0.2338E 00	0.2387E 00	0.2425E 00	0.2363E 00	0.2167E 00	0.1875E 00

F. FOR LOAD AT RADIAL POSITION NO=6

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1903E 00	0.1941E 00	0.2062E 00	0.2444E 00	0.3826E 00	0.8154E 00
2	0.1903E 00	0.1938E 00	0.2034E 00	0.2249E 00	0.2644E 00	0.3036E 00
3	0.1903E 00	0.1933E 00	0.1985E 00	0.2039E 00	0.2042E 00	0.1934E 00
4	0.1903E 00	0.1930E 00	0.1964E 00	0.1965E 00	0.1897E 00	0.1760E 00

TABLE 7 - EXAMPLE 4

A. FOR LOAD AT RADIAL POSITION NO=1

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2673E 01	0.1163E 1	0.6460E 00	0.4509E 00	0.3486E 00	0.2830E 00
2	0.2663E 01	0.1162E 01	0.6459E 00	0.4508E 00	0.3486E 00	0.2830E 00
3	0.2656E 01	0.1161E 01	0.6457E 00	0.4508E 00	0.3486E 00	0.2830E 00

B. FOR LOAD AT RADIAL POSITION NO=2

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1150E 01	0.1459E 01	0.7569E 00	0.4827E 00	0.3603E 00	0.2896E 00
2	0.1150E 01	0.1295E 01	0.7236E 00	0.4791E 00	0.3607E 00	0.2893E 00
3	0.1150E 01	0.1211E 01	0.6981E 00	0.4755E 00	0.3606E 00	0.2897E 00

C. FOR LOAD AT RADIAL POSITION NO=3

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.6483E 00	0.7540E 00	0.1179E 01	0.6178E 00	0.3980E 00	0.3009E 00
2	0.6484E 00	0.7269E 00	0.84[illegible]0E 00	0.5438E 00	0.3843E 00	0.3011E 00
3	0.6484E 00	0.7100E 00	0.7124E 00	0.5031E 00	0.3770E 00	0.3003E 00

D. FOR LOAD AT RADIAL POSITION NO=4

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.4525E 00	0.4818E 00	0.6115E 00	0.1034E 01	0.5384E 00	0.3407E 00
2	0.4526E 00	0.4781E 00	0.5431E 00	0.6114E 00	0.4357E 00	0.3215E 00
3	0.4526E 00	0.4755E 00	0.5091E 00	0.4942E 00	0.3883E 00	0.3103E 00

E. FOR LOAD AT RADIAL POSITION NO=5

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.3506E 00	0.3612E 00	0.3970E 00	0.5331E 00	0.9245E 00	0.4773E 00
2	0.3506E 00	0.3607E 00	0.3863E 00	0.4360E 00	0.4774E 00	0.3582E 00
3	0.3506E 00	0.3603E 00	0.3793E 00	0.3956E 00	0.3783E 00	0.3039E 00

F. FOR LOAD AT RADIAL POSITION NO=6

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2855E 00	0.2904E 00	0.3030E 00	0.3392E 00	0.4724E 00	0.8982E 00
2	0.2855E 00	0.2904E 00	0.3016E 00	0.3231E 00	0.3592E 00	0.3916E 00
3	0.2855E 00	0.2903E 00	0.3003E 00	0.3129E 00	0.3186E 00	0.3039E 00

TABLE 8 - EXAMPLE 5

A. FOR LOAD AT RADIAL POSITION NO=1

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.3556E 01	0.1550E 01	0.8612E 00	0.6011E 00	0.4648E 00	0.3773E 00
2	0.3549E 01	0.1549E 01	0.8611E 00	0.6011E 00	0.4648E 00	0.3773E 00

B. FOR LOAD AT RADIAL POSITION NO=2

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1533E 01	0.1840E 01	0.9836E 00	0.6414E 00	0.4813E 00	0.3865E 00
2	0.1533E 01	0.1710E 01	0.9593E 00	0.6375E 00	0.4805E 00	0.3857E 00

C. FOR LOAD AT RADIAL POSITION NO=3

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.8645E 00	0.9856E 00	0.1394E 01	0.7776E 00	0.5183E 00	0.4022E 00
2	0.8645E 00	0.9661E 00	0.1019E 01	0.7154E 00	0.5127E 00	0.4006E 00

D. FOR LOAD AT RADIAL POSITION NO=4

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.6034E 00	0.6394E 00	0.7735E 00	0.1183E 01	0.6606E 00	0.4384E 00
2	0.6034E 00	0.6370E 00	0.7167E 00	0.7841E 00	0.5687E 00	0.4278E 00

E. FOR LOAD AT RADIAL POSITION NO=5

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.4675E 00	0.4811E 00	0.5214E 00	0.6574E 00	0.1040E 01	0.5751E 00
2	0.4675E 00	0.4809E 00	0.5137E 00	0.5716E 00	0.6090E 00	0.4612E 00

F. FOR LOAD AT RADIAL POSITION NO=6

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.3806E 00	0.3871E 00	0.4026E 00	0.4408E 00	0.5723E 00	0.9914E 00
2	0.3806E 00	0.3871E 00	0.4009E 00	0.4288E 00	0.4686E 00	0.4969E 00

TABLE 9 - EXAMPLE 6

A. FOR LOAD AT RADIAL POSITION NO=1

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.5330E 01	0.2324E 01	0.1292E 01	0.9017E 00	0.6972E 00	0.5660E 00
2	0.5326E 01	0.2324E 01	0.1292E 01	0.9017E 00	0.6971E 00	0.5660E 00

B. FOR LOAD AT RADIAL POSITION NO=2

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2300E 01	0.2670E 01	0.1455E 01	0.9582E 00	0.7209E 00	0.5793E 00
2	0.2300E 01	0.2591E 01	0.1447E 01	0.9582E 00	0.7214E 00	0.5786E 00

C. FOR LOAD AT RADIAL POSITION NO=3

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1297E 01	0.1464E 01	0.1892E 01	0.1121E 01	0.7750E 00	0.6012E 00
2	0.1297E 01	0.1454E 01	0.1690E 01	0.1088E 01	0.7686E 00	0.6022E 00

D. FOR LOAD AT RADIAL POSITION NO=4

ECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.9051E 00	0.9573E 00	0.1121E 01	0.1528E 01	0.9267E 00	0.6511E 00
2	0.9051E 00	0.9562E 00	0.1086E 01	0.1223E 01	0.8714E 00	0.6429E 00

E. FOR LOAD AT RADIAL POSITION NO=5

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.7013E 00	0.7215E 00	0.7763E 00	0.9287E 00	0.1303E 01	0.7812E 00
2	0.7013E 00	0.7214E 00	0.7725E 00	0.8721E 00	0.9548E 00	0.7163E 00

F. FOR LOAD AT RADIAL POSITION NO=6

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.5709E 00	0.5807E 00	0.6033E 00	0.6521E 00	0.7910E 00	0.1202E 01
2	0.5709E 00	0.5807E 00	0.6032E 00	0.6463E 00	0.7185E 00	0.7831E 00

TABLE 10- EXAMPLE 7

LOAD POSN.	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1066E 02	0.4648E 01	0.2583E 01	0.1803E 01	0.1394E 01	0.1132E 01
2	0.4600E 01	0.5261E 01	0.2902E 01	0.1916E 01	0.1442E 01	0.1158E 01
3	0.2594E 01	0.2918E 01	0.3562E 01	0.2208E 01	0.1544E 01	0.1203E 01
4	0.1810E 01	0.1913E 01	0.2207E 01	0.2751E 01	0.1798E 01	0.1294E 01
5	0.1403E 01	0.1443E 01	0.1549E 01	0.1801E 01	0.2258E 01	0.1498E 01
6	0.1142E 01	0.1161E 01	0.1206E 01	0.1298E 01	0.1510E 01	0.1985E 01

TABLE 11- EXAMPLE 9

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.1739E 01	0.1788E 01	0.1796E 01	0.1744E 01	0.1603E 01	0.1361E 01
2	0.1667E 01	0.1517E 01	0.1286E 01	0.1086E 01	0.8939E 00	0 6925E 00
3	0.1490E 01	0.1183E 01	0.8954E 00	0.7164E 00	0.5770E 00	0.4567E 00
4	0.1254E 01	0.9171E 00	0.6775E 00	0.5420E 00	0.4415E 00	0.3643E 00
5	0.1008E 01	0.7261E 00	0.5485E 00	0.4432E 00	0.3672E 00	0.3081E 00
6	0.7934E 00	0.5927E 00	0.4645E 00	0.3804E 00	0.3189E 00	0.2702E 00
7	0.6398E 00	0.5031E 00	0.4071E 00	0.3370E 00	0.2849E 00	0.2440E 00
8	0.5593E 00	0.4484E 00	0.3681E 00	0.3066E 00	0.2606E 00	0.2249E 00
9	0.5471E 00	0.4213E 00	0.3429E 00	0.2854E 00	0.2433E 00	0.2110E 00
10	0.5840E 00	0.4141E 00	0.3279E 00	0.2714E 00	0.2315E 00	0.2013E 00
11	0.6419E 00	0.4178E 00	0.3199E 00	0.2626E 00	0.2238E 00	0.1949E 00
12	0.6919E 00	0.4243E 00	0.3164E 00	0.2579E 00	0.2196E 00	0.1914E 00
13	0.7114E 00	0.4272E 00	0.3154E 00	0.2564E 00	0.2182E 00	0.1902E 00

TABLE 12- EXAMPLE 8

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.2450E 01	0.2215E 01	0.2111E 01	0.2000E 01	0.1821E 01	0.1552E 01
2	0.2359E 01	0.1941E 01	0.1602E 01	0.1344E 01	0.1113E 01	0.8839E 00
3	0.2132E 01	0.1601E 01	0.1215E 01	0.9790E 00	0.8008E 00	0.6516E 00
4	0.1838E 01	0.1331E 01	0.1005E 01	0.8134E 00	0.6730E 00	0.5656E 00
5	0.1555E 01	0.1147E 01	0.8914E 00	0.7286E 00	0.6106E 00	0.5191E 00
6	0.1353E 01	0.1041E 01	0.8326E 00	0.6869E 00	0.5795E 00	0.4950E000
7	0.1280E 01	0.1006E 01	0.8142E 00	0.6741E 00	0.5699E 00	0.4880E 00

TABLE 13- EXAMPLE 10

SECTOR	RADIAL POSITIONS 1	2	3	4	5	6
1	0.7528E 02	0.7418E 02	0.7181E 02	0.6834E 02	0.6295E 02	0.5500E002

TABLE 14 - POLYNOMIAL CO-EFFICIENTS

A. FOR SECTOR 1

-0.17029E 04	0.17271E 05	-0.12033E 06	0.34285E 06	-0.34223E 06
0.11923E 06	-0.21030E 07	0.14702E 08	-0.41975E 08	0.41955E 08
-0.20955E 07	0.40703E 08	-0.28475E 09	0.81328E 09	-0.81310E 09
0.58779E 07	-0.11561E 09	0.80887E 09	-0.23104E 10	0.23099E 10
-0.43014E 07	0.84972E 08	-0.59452E 09	0.16981E 10	-0.16978E 10
0.19546E 04	-0.20141E 05	0.14032E 06	-0.39978E 06	0.39905E 06
-0.13835E 06	0.24520E 07	-0.17142E 08	0.48939E 08	-0.48915E 08
0.24379E 07	-0.47453E 08	-0.33197E 09	-0.94814E 09	0.94792E 09
-0.68406E 07	0.13478E 09	-0.94298E 09	0.26934E 10	-0.26928E 10
0.50065E 07	-0.99060E 08	0.69308E 09	-0.19796E 10	0.19792E 10
-0.79139E 03	0.82784E 04	-0.57672E 05	0.16430E 06	-0.16400E 06
0.56606E 05	-0.10077E 07	0.70446E 07	-0.20112E 08	0.20102E 08
-0.99985E 06	0.19499E 08	-0.13641E 09	0.38961E 09	-0.38952E 09
0.28064E 07	-0.55383E 08	0.38748E 09	-0.11067E 10	0.11065E 10
-0.20542E 07	0.40704E 08	-0.28479E 09	0.81343E 09	-0.81326E 09
0.13494E 03	-0.14280E 04	0.99486E 04	-0.28343E 05	0.28291E 05
-0.97320E 04	0.17383E 06	-0.12152E 07	0.34694E 07	-0.34677E 07
0.17221E 06	-0.33634E 07	0.23530E 08	-0.67203E 08	0.67187E 08
-0.48348E 06	0.95526E 07	-0.66834E 08	0.19089E 09	-0.19085E 09
0.35391E 06	-0.70207E 07	0.49120E 08	-0.14030E 09	0.14027E 09
-0.82419E 01	0.87976E 02	-0.61293E 03	0.17463E 04	-0.17431E 04
0.59815E 03	-0.10710E 05	0.74875E 05	-0.21376E 06	0.21366E 06
-0.10598E 05	0.20721E 06	-0.14496E 07	0.41402E 07	-0.41392E 07
0.29759E 05	-0.58848E 06	0.41173E 07	-0.11760E 08	0.11758E 08
-0.21785E 05	0.43250E 06	-0.30260E 07	0.86431E 07	-0.86413E 07
0.36749E 04	-0.37464E 05	0.26091E 06	-0.74317E 06	0.74171E 06
-0.25780E 06	0.45566E 07	-0.31852E 08	0.90929E 08	-0.90881E 08
0.45353E 07	-0.88171E 08	0.61680E 09	-0.17616E 10	0.17611E 10
-0.12723E 08	0.25044E 09	-0.17521E 10	0.50042E 10	-0.50031E 10
0.93113E 07	-0.18407E 09	0.12878E 10	-0.36782E 10	0.36774E 10
-0.42181E 04	0.43553E 05	-0.30328E 06	0.86381E 06	-0.86209E 06
0.29849E 06	-0.52957E 07	0.37017E 08	-0.10567E 09	0.10562E 09
-0.52616E 07	0.10246E 09	-0.71676E 09	0.20471E 10	-0.20465E 10
0.14765E 08	-0.29102E 09	0.20360E 10	-0.58151E 10	0.58138E 10
-0.10806E 08	0.21389E 09	-0.14964E 10	0.42741E 10	-0.42731E 10
0.17081E 04	-0.17863E 05	0.12439E 06	-0.35427E 06	0.35355E 06
-0.12196E 06	0.21718E 07	-0.15180E 08	0.43335E 08	-0.43311E 08
0.21540E 07	-0.42015E 08	0.29391E 09	-0.83939E 09	0.83917E 09
-0.60460E 07	0.11933E 09	-0.83483E 09	0.23844E 10	-0.23838E 10
0.44254E 07	-0.87702E 08	0.61358E 09	-0.17525E 10	0.17521E 10
-0.29132E 03	0.30770E 04	-0.21427E 05	0.61026E 05	-0.60903E 05
0.20949E 05	-0.37410E 06	0.26150E 07	-0.7 650E 07	0.74609E 07
-0.37056E 06	0.72368E 07	-0.50623E 08	0.14458E 09	-0.14454E 09
0.10403E 07	-0.20553E 08	0.14379E 09	-0.41068E 09	0.41059E 09

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-0.76150E 06 0.15105E 08-0.10568E 09 0.30184E 09-0.30178E 09
 0.17799E 02-0.18938E 03 0.13188E 04-0.37562E 04 0.37487E 04
-0.12868E 04 0.23027E 05-0.16096E 06 0.45949E 06-0.45924E 06
 0.22786E 05-0.44539E 06 0.31157E 07-0.88984E 07 0.88961E 07
-0.63977E 05 0.12649E 07-0.88494E 07 0.2 275E 08-0.25270E 08
 0.46833E 05-0.92963E 06 0.65039E 07-0.18576E 08 0.18572E 08
-0.27497E 04 0.28046E 05-0.19519E 06 0.55576E 06-0.55454E 06
 0.19259E 06-0.34055E 07 0.23801E 08-0.67938E 08 0.67897E 08
-0.33877E 07 0.65876E 08-0.46079E 09 0.13160E 10-0.13156E 10
 0.95035E 07-0.18710E 09 0.13089E 10-0.37382E 10 0.37372E 10
-0.69549E 07 0.13751E 09-0.96198E 09 0.27475E 10-0.27468E 10
 0.31690E 04-0.32720E 05 0.22771E 06-0.64830E 06 0.64685E 06
-0.22382E 06 0.39721E 07-0.27760E 08 0.79239E 08-0.79190E 08
 0.39446E 07-0.76829E 08 0.53740E 09-0.11347E 10 0.15343E 10
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 0.81008E 07-0.16036E 09 0.11219E 10-0.32042E 10 0.32034E 10
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 0.45448E 07-0.89710E 08 0.62756E 09-0.17923E 10 0.17919E 10
-0.33265E 07 0.65930E 08-0.46123E 09 0.13173E 10-0.13170E 10
 0.22011E 03-0.23221E 04 0.16130E 05-0.46009E 05 0.45905E 05
-0.15785E 05 0.28188E 06-0.19700E 07 0.56232E 07-0.56197E 07
 0.27912E 06-0.54512E 07 0.38130E 08-0.10889E 09 0.10886E 09
-0.78354E 06 0.15481E 08-0.10830E 09 0.30930E 09-0.30923E 09
 0.57353E 06-0.11377E 08 0.79593E 08-0.22732E 09 0.22727E 09
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 0.97109E 03-0.17374E 05 0.12143E 06-0.34660E 06 0.34639E 06
-0.17188E 05 0.33597E 06-0.23500E 07 0.67114E 07-0.67095E 07
 0.48256E 05-0.95409E 06 0.66744E 07-0.19062E 08 0.19058E 08
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 0.91905E 03-0.93364E 04 0.64920E 05-0.18474E 06 0.18427E 06
-0.64040E 05 0.11310E 07-0.79026E 07 0.22554E 08-0.22538E 08
 0.11252E 07-0.21870E 08 0.15296E 09-0.43680E 09 0.43665E 09
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 0.23095E 07-0.45645E 08 0.31929E 09-0.91188E 09 0.91163E 09
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-0.13148E 07 0.25593E 08-0.17900E 09 0.51116E 09-0.51099E 09
 0.36885E 07-0.72681E 08 0.50139E 09-0.14519E 10 0.14515E 10
-0.26994E 07 0.53414E 08-0.37364E 09 0.10671E 10-0.10668E 10
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-0.30684E 05 0.54567E 06-0.38126E 07 0.10881E 08-0.10873E 08
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0.11840E 05	-0.23489E 06	0.16431E 07	-0.46926E 07	0.46913E 07
-0.14056E 03	0.14178E 04	-0.98451E 04	0.27993E 05	-0.27907E 05
0.97158E 04	-0.17116E 06	0.11955E 07	-0.34111E 07	0.34083E 07
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0.47780E 06	-0.93939E 07	0.65699E 08	-0.18761E 09	0.18755E 09
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0.19960E 06	-0.38810E 07	0.27138E 08	-0.77490E 08	0.77459E 08
-0.55981E 06	0.11020E 08	-0.77073E 08	0.22009E 09	-0.22001E 09
0.40964E 06	-0.80985E 07	0.56642E 08	-0.11175E 09	0.16170E 09
-0.66678E 02	0.68716E 03	-0.47711E 04	0.13565E 05	-0.13523E 05
0.46769E 04	-0.82934E 05	0.57924E 06	-0.16528E 07	0.16513E 07
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0.23091E 06	-0.45510E 07	0.31829E 08	-0.90891E 08	0.90859E 08
-0.16898E 06	0.33444E 07	-0.23391E 08	0.66797E 08	-0.66774E 08
0.11454E 02	-0.11894E 03	0.82592E 03	-0.23483E 04	0.23410E 04
-0.80782E 03	0.14358E 05	-0.10028E 06	0.28614E 06	-0.28590E 06
0.14236E 05	-0.27748E 06	0.19403E 07	-0.55404E 07	0.55382E 07
-0.39942E 05	0.78788E 06	-0.55103E 07	0.15735E 08	-0.15730E 08
0.29231E 05	-0.57897E 06	0.40494E 07	-0.11564E 08	0.11560E 08
-0.70372E 00	0.73453E 01	-0.51 10E 02	0.14504E 03	-0.14460E 03
0.49824E 02	-0.88689E 03	0.61947E 04	-0.17676E 05	0.17661E 05
-0.87881E 03	0.17140E 05	-0.11986E 06	0.34225E 06	-0.34211E 06
0.24659E 04	-0.48668E 05	0.34038E 06	-0.97199E 06	0.97166E 06
-0.18046E 04	0.35763E 05	-0.25013E 06	0.71431E 06	-0.71407E 06
0.80046E 01	-0.79977E 02	0.55440E 03	-0.15747E 04	0.15688E 04
-0.54765E 03	0.96137E 04	-0.67115E 05	0.19145E 06	-0.19125E 06
0.958455 04	-0.18578E 06	0.12988E 07	-0.37081E 07	0.37063E 07
-0.26866E 05	0.52751E 06	-0.36886E 07	0.10532E 08	-0.10528E 08
0.19655E 05	-0.38764E 06	0.27108E 07	-0.77403E 07	0.77372E 07
-0.93149E 01	0.94023E 02	-0.65172E 03	0.18510E 04	-0.18440E 04
.64162E 03	-0.11300E 05	0.78885E 05	-0.22502E 06	0.22479E 06
-0.11249E 05	0.21837E 06	-0.15266E 07	0.43585E 07	-0.43563E 07
0.31539E 05	-0.62003E 06	0.43355E 07	-0.12379E 08	0.12374E 08
-0.23075E 05	0.45563E 06	-0.31861E 07	0.90976E 07	-0.90939E 07
0.38153E 01	-0.38882E 02	0.26951E 03	-0.76546E 03	0.76256E 03
-0.26454E 03	0.46729E 04	-0.32621E 05	0.93052E 05	-0.92955E 05
0.46459E 04	-0.90306E 05	0.63134E 06	-0.18025E 07	0.18016E 07
-0.13028E 05	0.25641E 06	-0.17930E 07	0.51194E 07	-0.51172E 07
0.95327E 04	-0.18842E 06	0.13176E 07	-0.37623E 07	0.37607E 07
-0.65653E 00	0.67349E 01	-0.46687E 02	0.13261E 03	-0.13211E 03
0.45739E 02	-0.80962E 03	0.56521E 04	-0.16123E 05	0.16106E 05
-0.80431E 03	0.15649E 05	-0.10940E 06	0.31235E 06	-0.31219E 06
0.22559E 04	-0.44432E 05	0.31069E 06	-0.88711E 06	0.88674E 06
-0.16506E 04	0.32650E 05	-0.22832E 06	0.65193E 06	-0.65167E 06
0.40392E-01	-0.41603E 00	0.28843E 01	-0.81932E 01	0.81628E 01
-0.28228E 01	0.50030E 02	-0.34928E 03	0.99636E 03	-0.99535E 03
0.49682E 02	-0.96718E 03	0.67619E 04	-0.19305E 05	0.19296E 05
-0.13936E 03	0.27462E 04	-0.19203E 05	0.54830E 05	-0.54808E 05
0.10197E 03	-0.20179E 04	0.14111E 05	-0.40294E 05	0.40278E 05

B. FOR SECTOR 2

-0.40268E 03	0.27720E 04	-0.18464E 05	0.51151E 05	-0.50130E 05
0.18877E 05	-0.29920E 06	0.20631E 07	-0.58414E 07	0.58074E 07
-0.30191E 06	0.56271E 07	-0.39108E 08	0.11125E 09	-0.11095E 09
0.83598E 06	-0.15926E 08	0.11080E 09	-0.31541E 09	0.31467E 09
-0.60908E 06	0.11692E 08	-0.81370E 08	0.20168E 09	-0.23117E 09
0.44476E 03	-0.31310E 04	0.20104E 05	-0.5 540E 05	0.56331E 05
-0.21003E 05	0.33559E 06	-0.23121E 07	0.65429E 07	-0.65027E 07
0.33674E 06	-0.62983E 07	0.43754E 08	-0.12444E 09	0.12408E 09
-0.93276E 06	0.17821E 08	-0.12394E 09	0.35273E 09	-0.35185E 09
0.67969E 06	-0.13081E 08	0.91012E 08	-0.25908E 09	0.25847E 09
-0.17310E 03	0.12318E 04	-0.81611E 04	0.22530E 05	-0.22029E 05
0.81728E 04	-0.13096E 06	0.90137E 06	-0.25492E 07	0.25325E 07
-0.13092E 06	0.24514E 07	-0.17022E 08	0.48397E 08	-0.48246E 08
0.36260E 06	-0.69339E 07	0.48203E 08	-0.13715E 09	0.13679E 09
-0.26421E 06	0.50892E 07	-0.35394E 08	0.10073E 09	-0.10048E 09
0.28490E 02	-0.20372E 03	0.13468E 04	-0.37127E 04	0.36267E 04
-0.13420E 04	0.21522E 05	-0.14102E 06	0.41841E 06	-0.41555E 06
0.21459E 05	-0.40191E 06	0.27896E 07	-0.79297E 07	0.79038E 07
-0.59418E 05	0.11365E 07	-0.78977E 07	0.22467E 08	-0.22404E 08
0.43292E 05	-0.83403E 06	0.57985E 07	-0.16499E 08	0.16456E 08
-0.16889E 01	0.12103E 02	-0.79884E 02	0.21999E 03	-0.21474E 03
0.79343E 02	-0.12726E 04	0.87477E 04	-0.24719E 05	0.24544E 05
-0.12662E 04	0.23713E 05	-0.16454E 06	0.4 764E 06	-0.46607E 06
0.35049E 04	-0.67033E 05	0.46572E 06	-0.13247E 07	0.13208E 07
-0.25534E 04	0.49190E 05	-0.34191E 06	0.97274E 06	-0.97010E 06
0.86018E 03	-0.59198E 04	0.39241E 05	-0.10837E 06	0.10598E 06
-0.39774E 05	0.63032E 06	-0.43391E 07	0.12273E 08	-0.12193E 08
0.63403E 06	-0.11811E 08	0.82021E 08	-0.23322E 09	0.23250E 09
-0.17547E 07	0.33412E 08	-0.23229E 09	0.66097E 09	-0.65923E 09
0.12783E 07	-0.24524E 08	0.17057E 09	-0.48545E 09	0.48424E 09
-0.95269E 03	0.66937E 04	-0.44253E 05	0.12199E 06	-0.11917E 06
0.44331E 05	-0.70734E 06	0.48649E 07	-0.13752E 08	0.13658E 08
-0.70768E 06	0.13224E 08	-0.91788E 08	0.26092E 09	-0.26007E 09
0.19590E 07	-0.37397E 08	0.25989E 09	-0.73932E 09	0.73726E 09
-0.14272E 07	0.27445E 08	-0.19081E 09	0.54295E 09	-0.54153E 09
0.37165E 03	-0.26360E 04	0.17375E 05	-0.47805E 05	0.46635E 05
-0.17274E 05	0.27618E 06	-0.18974E 07	0.53601E 07	-0.53212E 07
0.27532E 06	-0.51487E 07	0.35718E 08	-0.10150E 09	0.10115E 09
-0.76194E 06	0.14555E 08	-0.10110E 09	0.28753E 09	-0.28668E 09
0.55504E 06	-0.10680E 08	0.74223E 08	-0.21114E 09	0.21055E 09
-0.61282E 02	0.43637E 03	-0.28697E 04	0.78837E 04	-0.76829E 04
0.28396E 04	-0.45413E 05	0.31174E 06	-0.8 020E 06	0.87353E 06
- .45154E 05	0.84441E 06	-0.58554E 07	0.16635E 08	-0.16575E 08
0.12492E 06	-0.23862E 07	0.16569E 08	-0.47112E 08	0.46966E 08
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C.FOR SECTOR 3

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D.FOR SECTOR 4

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E.FOR SECTOR 5

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F.FOR SECTOR 6

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G.FOR SECTOR 7

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H.FOR SECTOR 8

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J.FOR SECTOR 10

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K.FOR SECTOR 11

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L.FOR SECTOR 12

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M.FOR SECTOR 13

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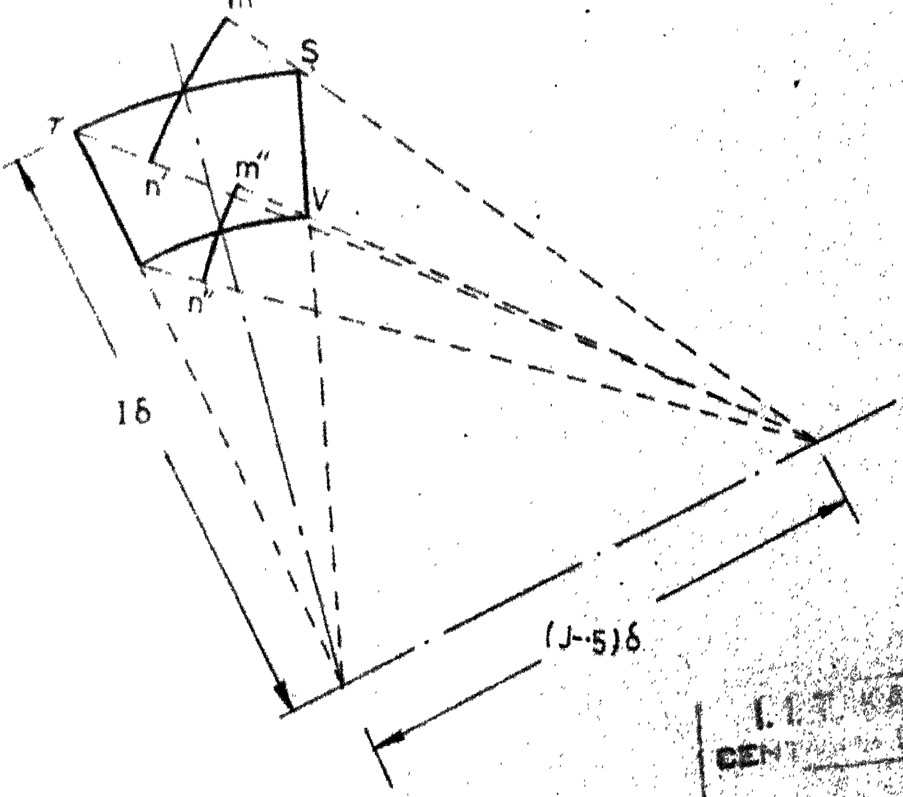

FIG. 3.1 APPROXIMATIONS FOR THE ELLIPTIC INTEGRALS IN REFERENCE NO. 6.

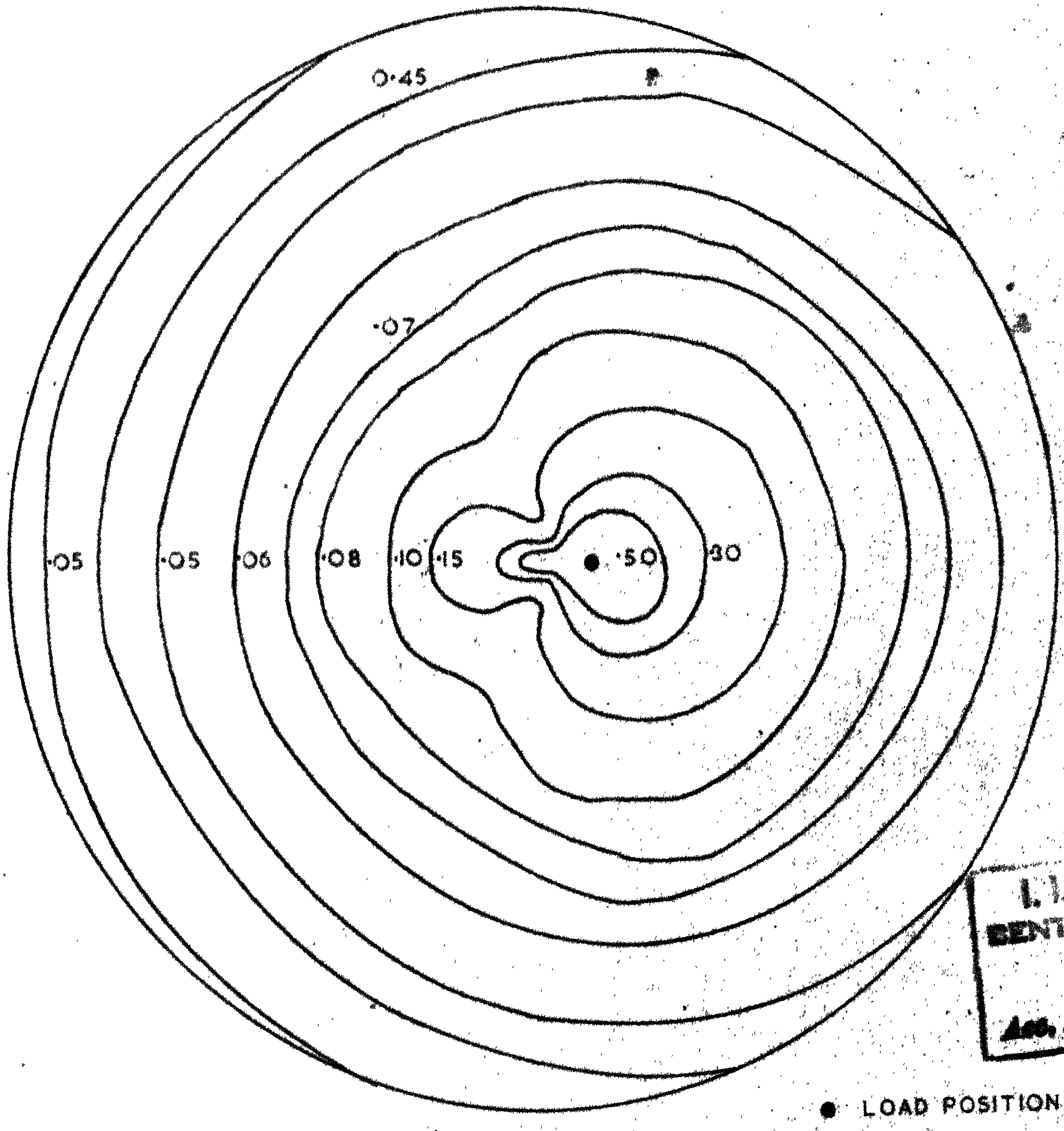

FIG. 3·2 DEFLECTION CONTOURS FOR A SINGLE CONCENTRAT
LOAD AT FIRST RADIAL POSITION FOR $\bar{D}$= ·01 AND μ

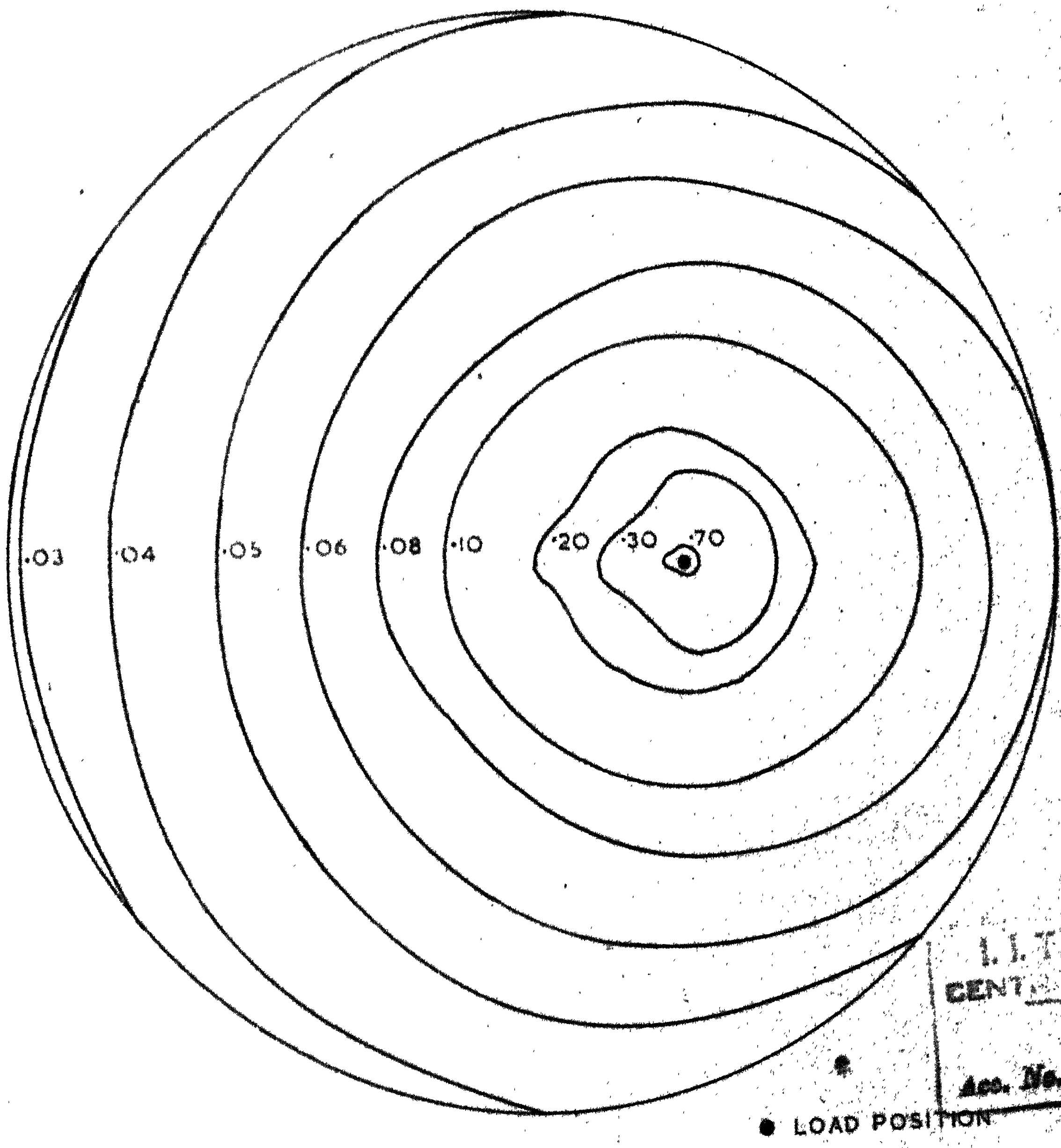

FIG. 3·3 DEFLECTION CONTOURS FOR A SINGLE LOAD AT SECO
RADIAL POSITION FOR $\bar{D}$=·01 AND μ = ·2

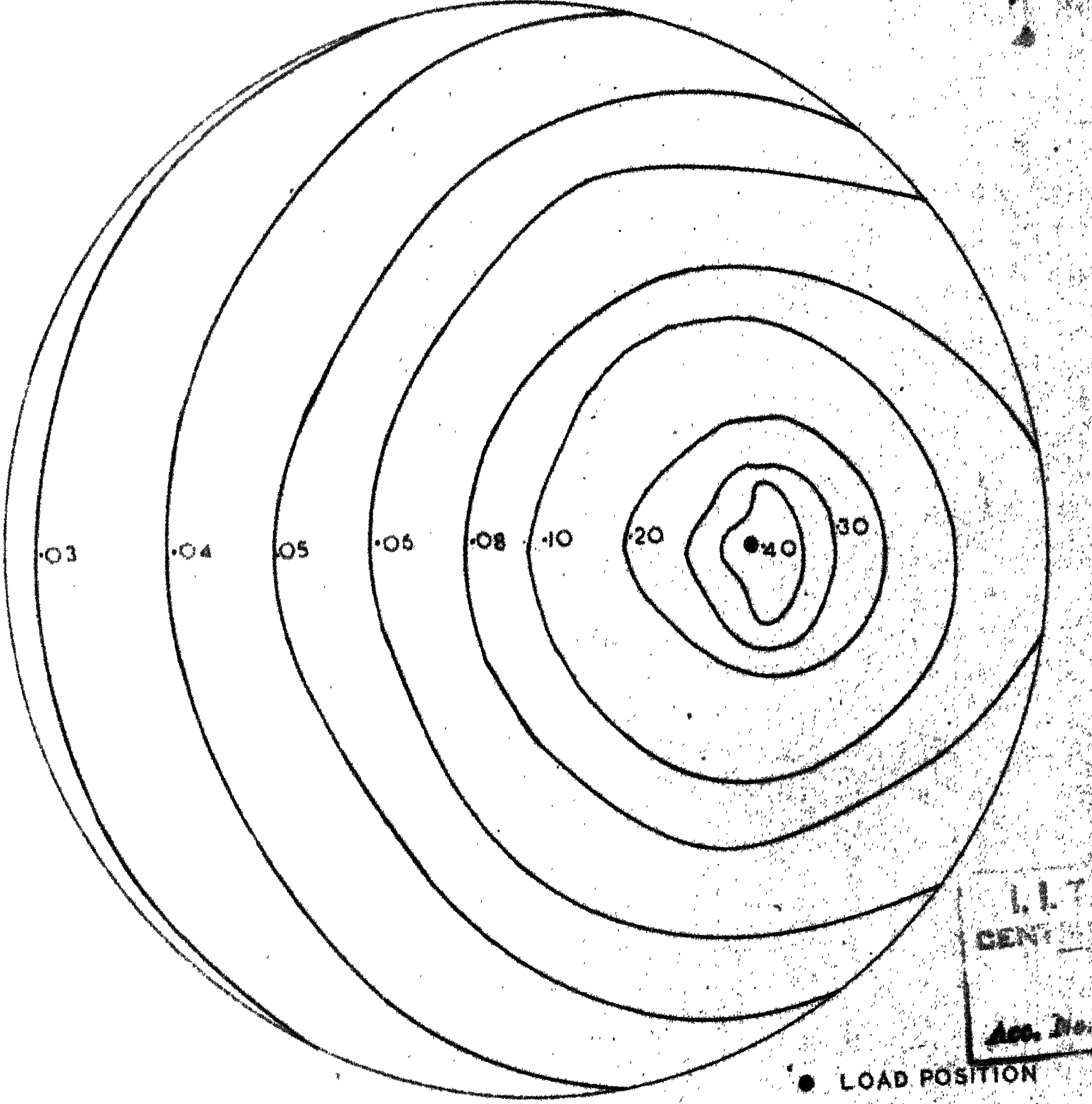

FIG. 3·4 DEFLECTION CONTOURS FOR A SINGLE LOAD AT THIRD RADIAL POSITION FOR $\bar{D}$= ·01 AND μ=·2

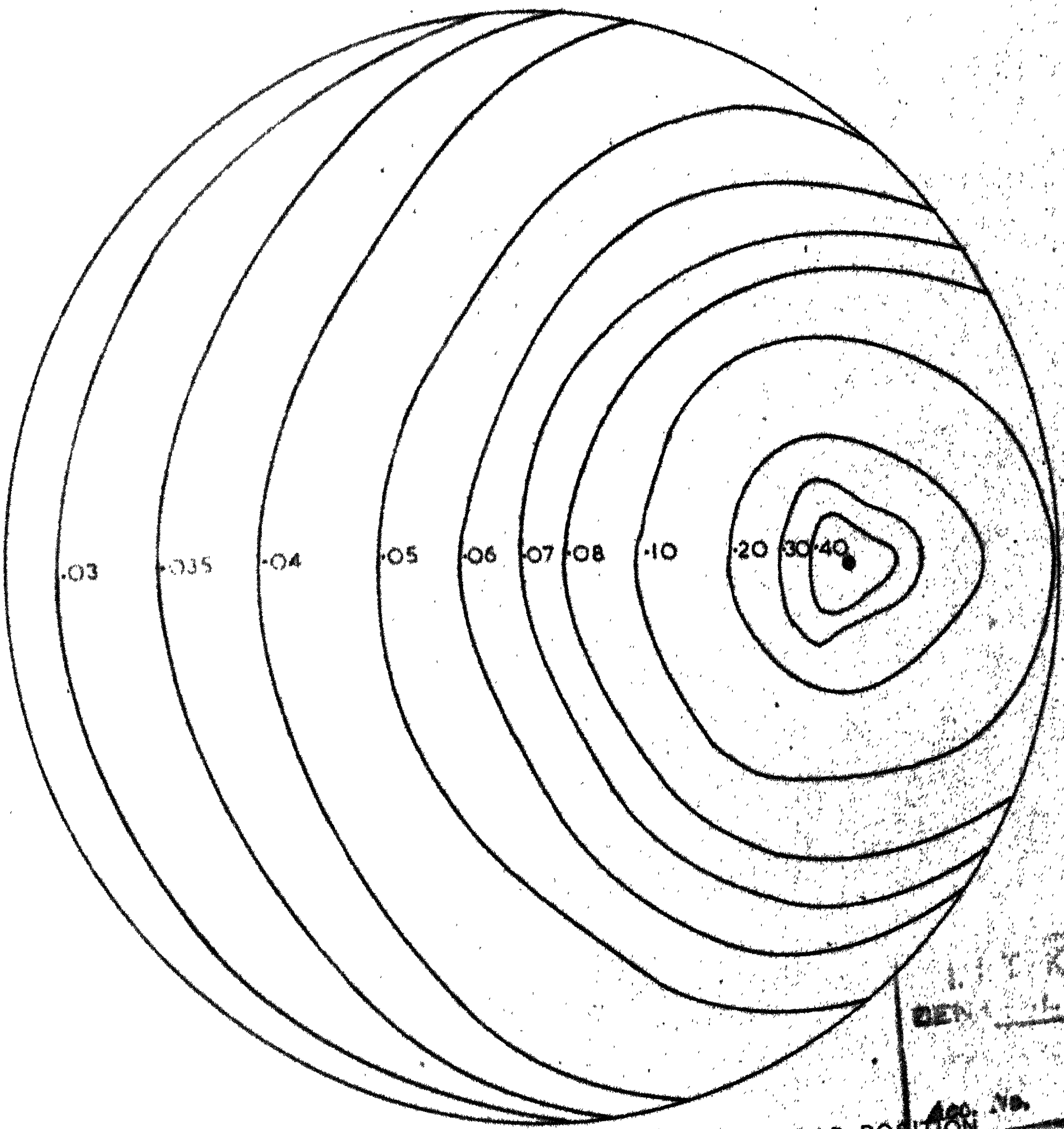

FIG. 3·5 DEFLECTION CONTOURS FOR A SINGLE LOAD AT FOURTH RADIAL POSITION FOR $\bar{D}$= ·01 AND μ=·2

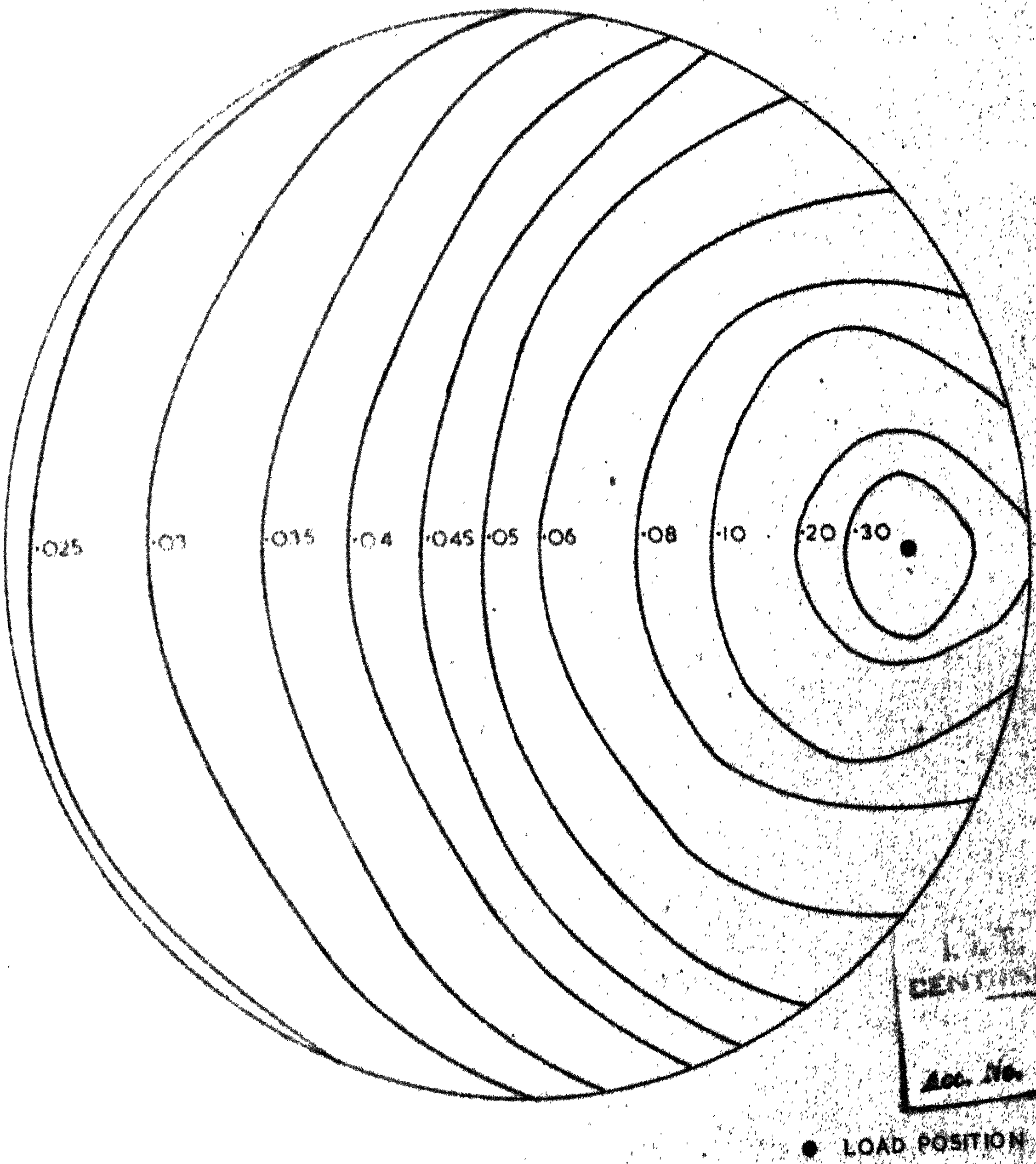

FIG. 3·6 DEFLECTION CONTOURS FOR A SINGLE CONCENTRATE
LOAD AT FIFTH RADIAL POSITION FOR $\bar{D}$=·01 AND μ=

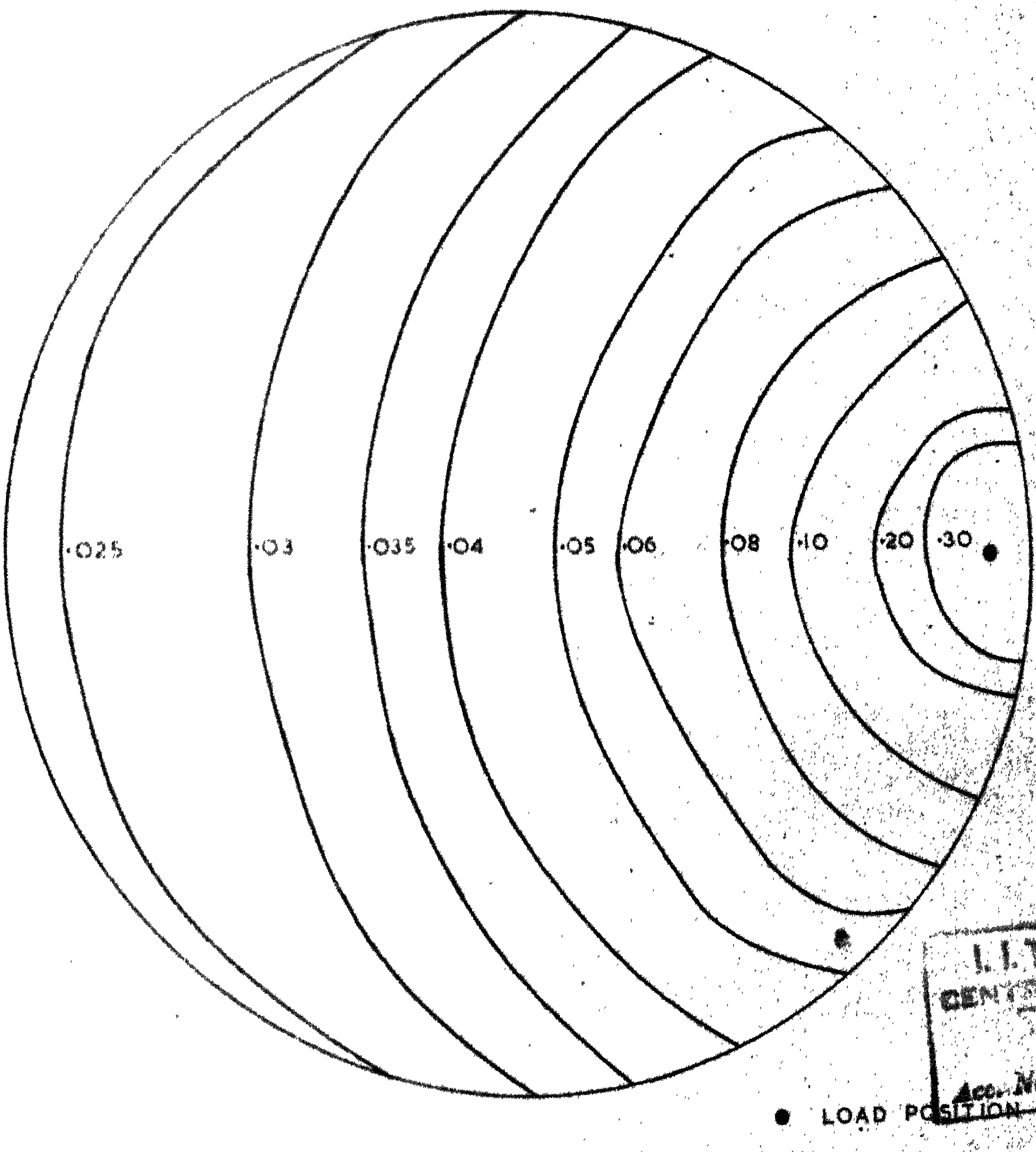

FIG. 3·7 DEFLECTION CONTOURS FOR A SINGLE CONCENTRA
LOAD AT SIXTH RADIAL POSITION FOR $\bar{D}$=·01 AND μ

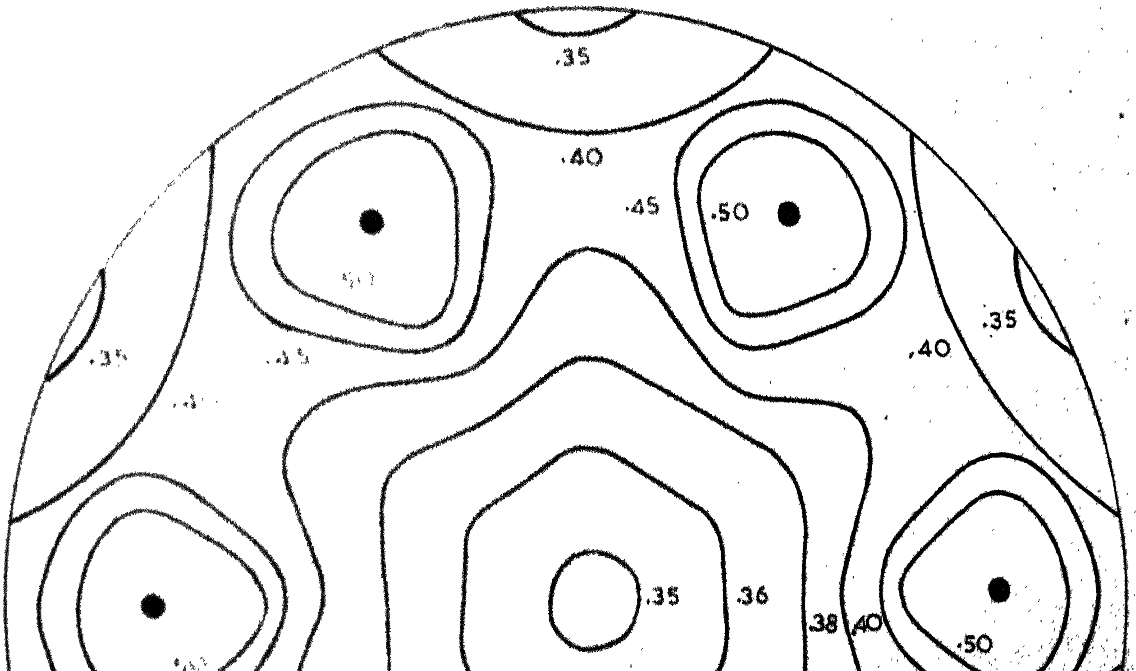

FIG. 3.8 DEFLECTION CONTOURS FOR SIX CONCENTRATED LOAD ON FIFTH PITCH CIRCLE FOR $\bar{D} = \cdot 01$

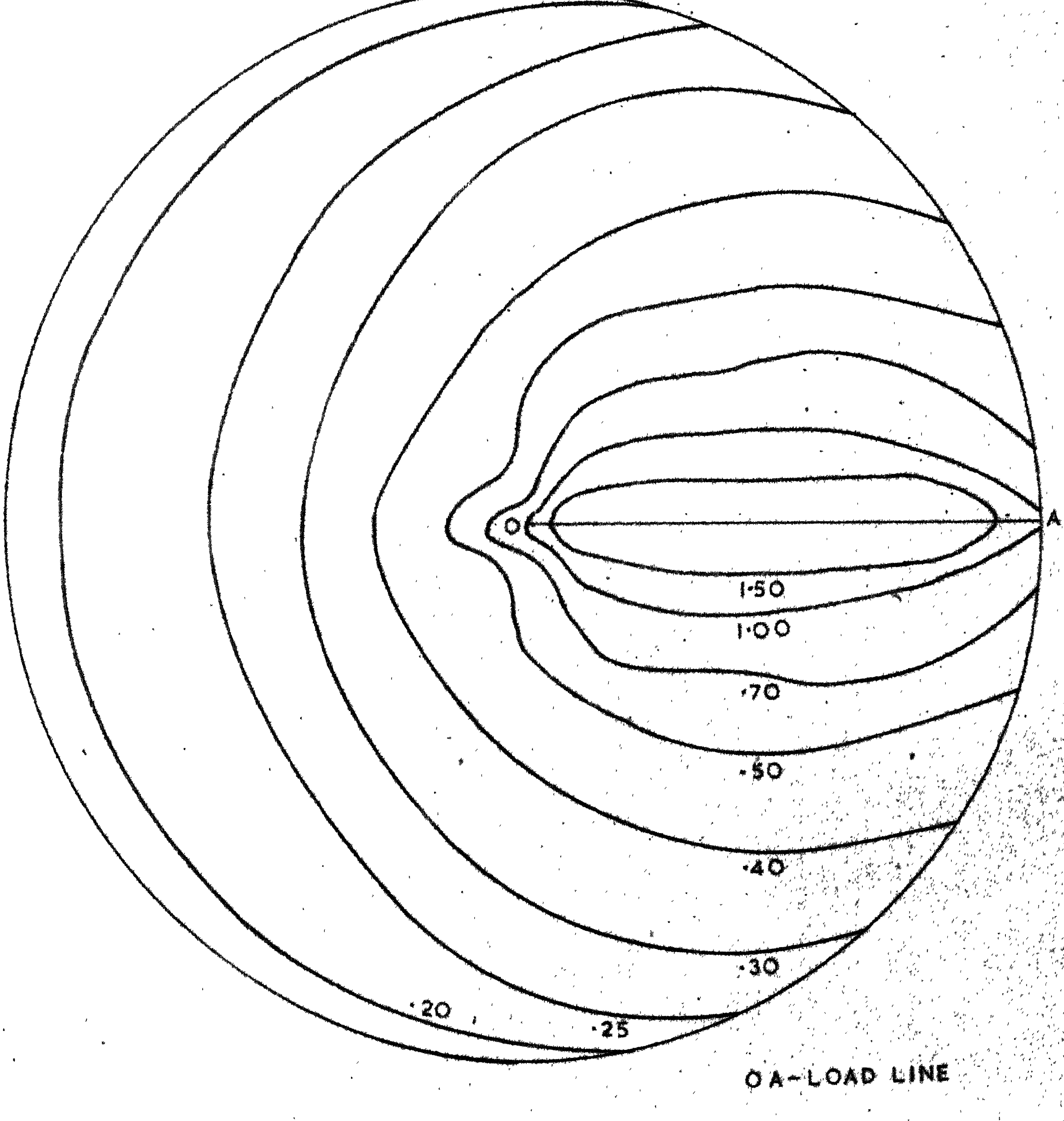

FIG. 3·9 DEFLECTION CONTOURS FOR RADIAL LINE LOAD FOR $\bar{D} = \cdot 01$ $\mu = \cdot 2$

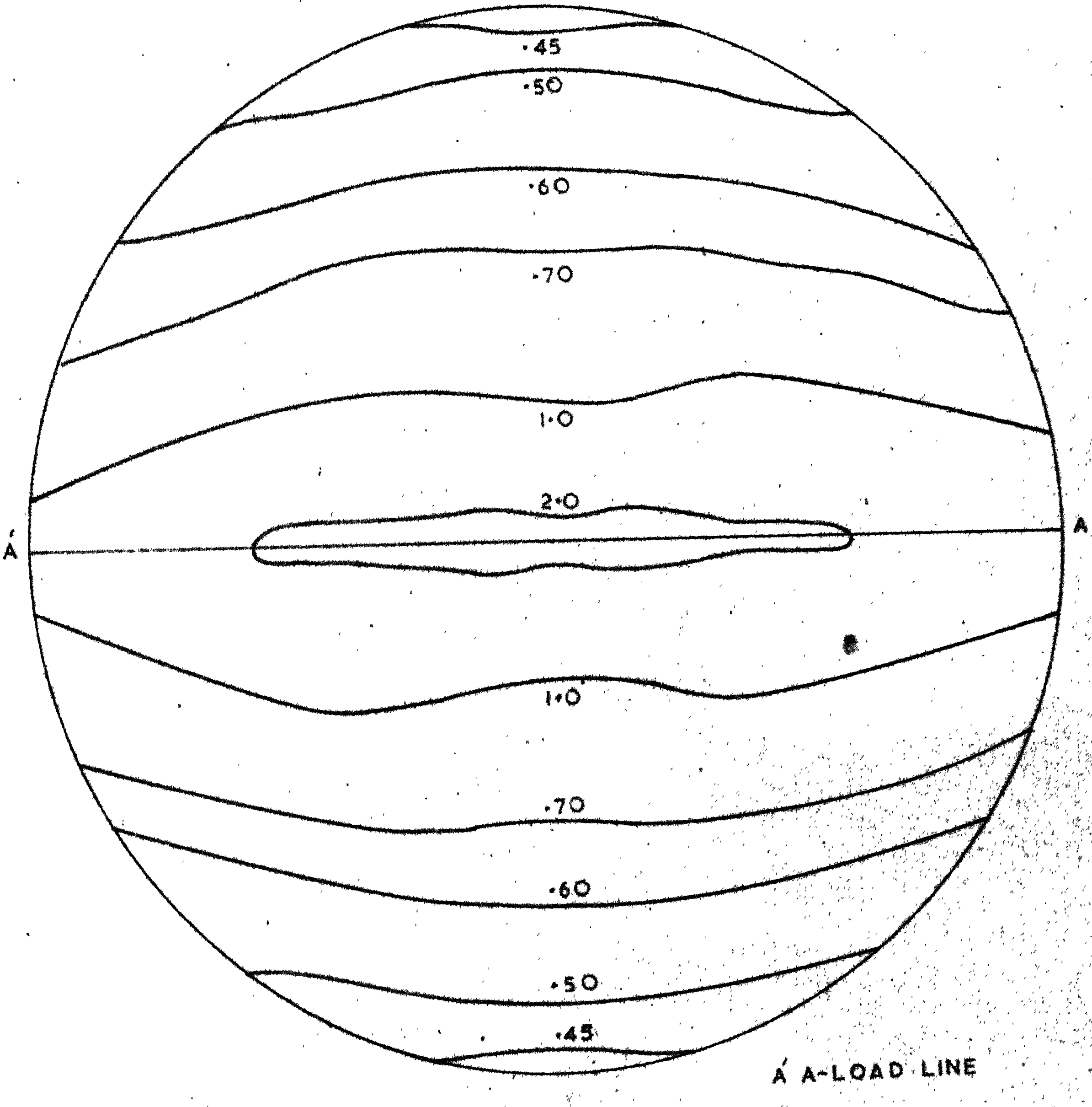

FIG. 3·10 DEFLECTION CONTOURS FOR A DIAMETRAL LINE LOAD FOR $\bar{D}$= ·01 AND μ= ·2

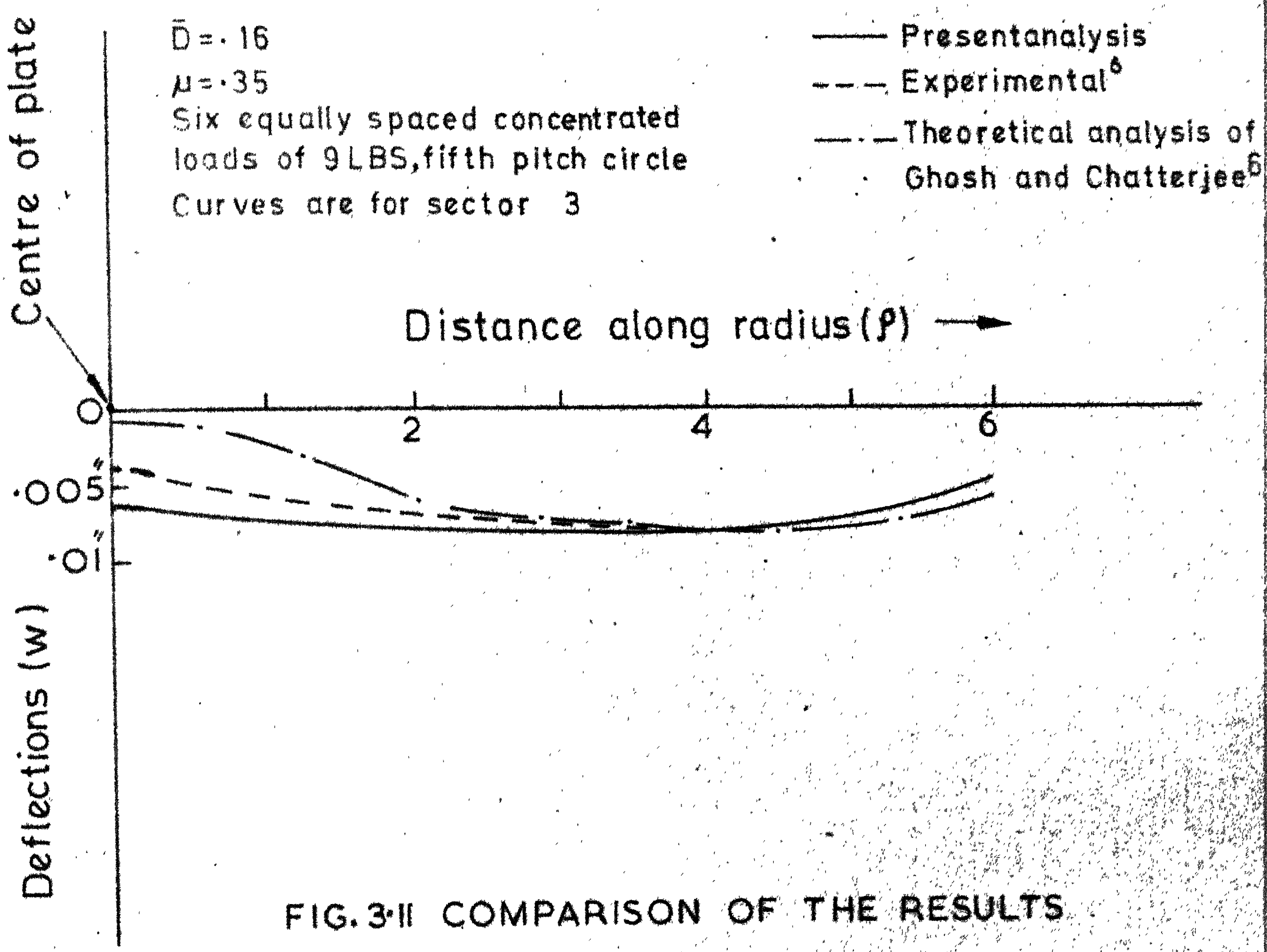

FIG. 3·11 COMPARISON OF THE RESULTS

CHAPTER IV

CONCLUSIONS

4.1 Relative Merits of the Proposed Method Over the Conventional Design Methods

The difficulty in presenting a rationalised design procedure for a circular raft lies in the proper assesment of intensity and distribution of contact pressure below the slab. Due to unpredictable behaviour of natural soils, as well as, the occurrence of different local conditions, the characteristics of the different element in a particular raft foundation problem are the essential requirements for design.

The conventional design procedures followed so far are not based on any sound basis and so the designer has to be guided by some ill-defined rules.

A solution of the problem has been presented by Hanna and Dawood[12], in which they have treated the raft by plate theory, assuming a uniform contact pressure distribution. The settlement of the soil is assumed to be axysymmetric. They have assumed

differential settlement of flexible raft to occur due to compaction of elastic soil mass below the raft foundation.

Two more recent works, one by Smith and Zar[31] and the other by Chu and Afandani[8], have detailed design procedures, applying thin plate theory. The first of these works deals with piled and raft foundations for chimneys. This method, though a valuable contribution to practical design aspects, is not theoretically justifiable. The solution is obtained for the raft foundation by superimposing the two loading cases of axially symmetrical ring loads and uniformly distributed loads on slabs, simply supported along edges. This design procedure is valid if the load is a ring load and it is symmetrically placed about the vertical axis through the centre of the raft.and the slab is simply supported by the chimney. In their work Chu and Afandani[8] have assumed a linear reactive pressure variation below the raft. Solutions are obtained considering this linear reactive pressure as the load on the circular raft, simply supported or fixed at the chimney wall. They have supplied a series of curves for different cases considered. This design procedure is also valid for only a ring loading case.

In a more recent work by Chatterjee and Ghosh[6], a more rationalised design procedure has been arrieved at. But their design procedure is valid only for six equally spaced concentrated loads and concentric loading case. The design procedure described in the present analysis is a generalisation of this work.

As in the case of Chatterjee and Ghosh[6], the main merit of the present method is that it does not assume the nature of contact pressure distribution. Equations are formulated eliminating this unknown pressure distribution from the condition of equilibrium and compatibility of the forces and deflected shape of the plate and the subgrade surface. The contact pressure distribution is a function of the rigidity of the plate and the properties of the plate and the subgrade material. This when assumed to be uniform or in linear variation is bound to set a major limitation to the validity of any suggested method. The main advantage of the present method over that of Chatterjee and Ghosh[6] is that this work is perfectly general and may be used for any type of particular loading case by proper superposition as shown in Examples I through X in the Chapter III. Another advantage of the method is that all the quantities are non-dimensional. And so by using this method solutions can be obtained for any plate dimension and any type of plate and subgrade material.

4.2 Conclusions

Based on this work involving analysis of circular elastic plates on elastic foundation several important conclusions can be drawn. These are as follows:

i) For a single concentrated load of a particular magnitude the maximum deflection is dependent on the load position and this maximum deflection becomes a minimum when the load is applied at the

fifth radial position for small values of $\bar{D}$ and at fourth radial position for moderate and larger values of $\bar{D}$. The same phenomenon takes place in case of the moments also.

ii) Very good aggrement between the experimental results and the results obtained by the present method is observed.

iii) With the help of the Polynomial Co-efficients and the program given in section 3.4, solution for circular plates of any dimension and material on any type of subgrade can be obtained for any type of loading with the help of a small computer. Even desk calculators can be used to get the solution.

iv) In case of Winkler type subgrade the same method of solution can be obtained much more easily by the present method of solution with the following modifications:

$\gamma(I,J,K) = 1$ for $I = J$ and $K = 1$ and all other $\gamma(I,J,K)$'s are zero,

and $\dfrac{(1-\nu'^2)}{\pi E_s \lambda \delta}$ is replaced by the reciprocal of the subgrade modulus.

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APPENDIX - A

Selection of the Proper Sign in Equations (2.16) and (2.17)

While calculating r_I by using equation (2.16) three cases may arise,

(i) The radius may, at some point on curve I, become tangential to curve I.

(ii) The radius r_I makes an acute angle with a line joining any point on curve I to the centre of the plate, at that point.

(iii) The radius of r_I makes an obtuse angle with a line joining any point on curve I to the centre of the plate, at that point.

Defining a the angle Ψ_{cr} as shown in Fig. A1 it is seen that in case I $(K+.5)\lambda > \Psi_{cr}$ and $(K-.5)\lambda < \Psi_{cr}$. In that case while integrating $\int r_I \, d\theta$ from θ_T to θ_{cr}, where $\theta_{cr} = \frac{\bar{\lambda}}{2} - \Psi_{cr}$ $r_I = \delta\left[(J-.5)\cos\theta - \sqrt{I^2-(J-.5)^2\sin^2\theta}\right]$ and while integrating from θ_{cr} to θ_T

$$r_I = \delta\left[(J-.5)\cos\theta + \sqrt{I^2-(J-.5)^2\sin^2\theta}\right]$$

In case II $(K+.5)\lambda \leq \Psi_{cr}$. In this case

$$r_I = \left[(J-.5)\cos\theta - \sqrt{I^2-(J-.5)^2\sin^2\theta}\right]\delta$$

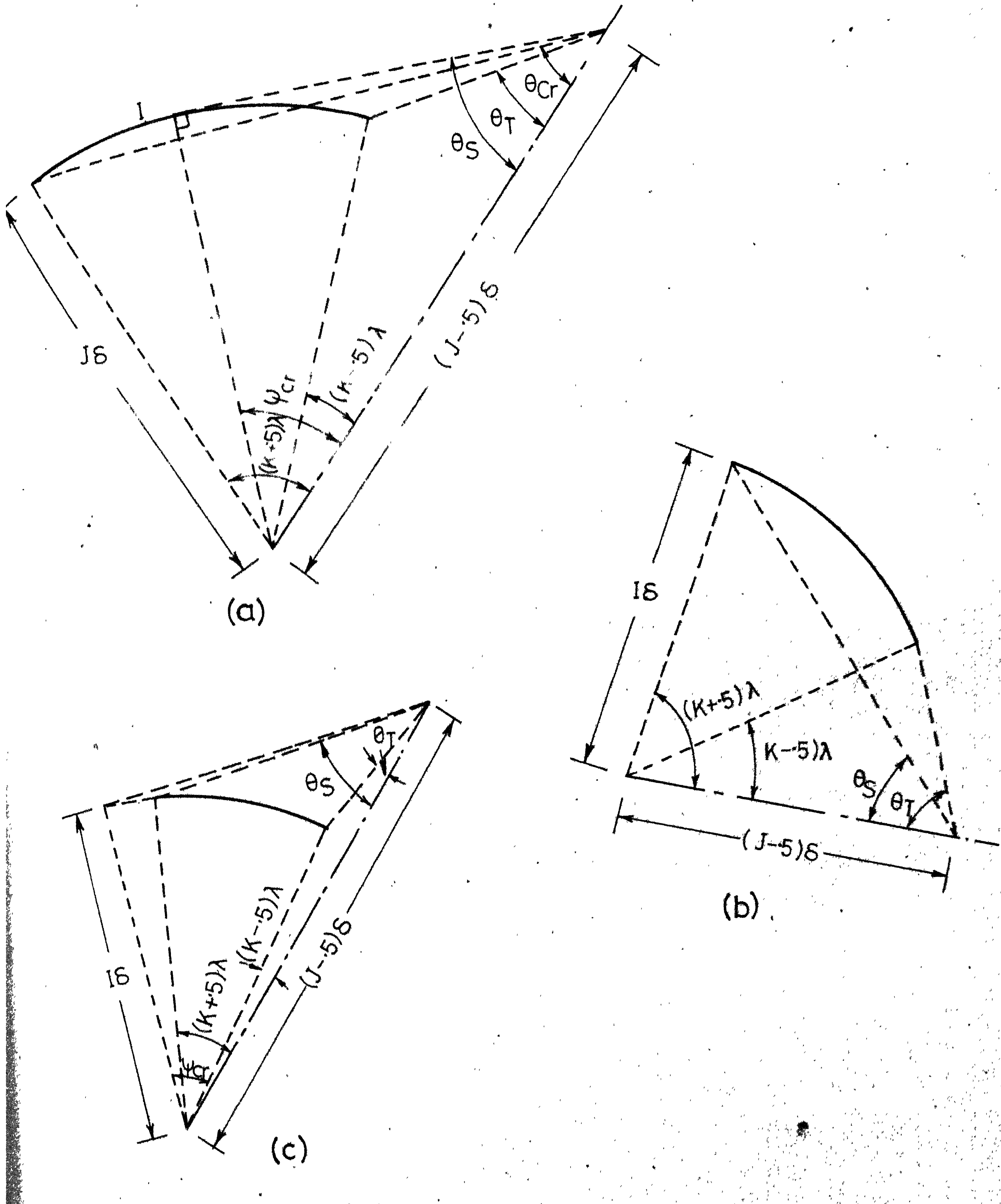
In case III $(K-.5)\lambda \geq \Psi_{cr}$. In this case

$$r_I = \left[(J-.5)\cos\theta + \sqrt{I^2-(J-.5)^2\sin^2\theta}\right]\delta$$

The above three cases are shown in Fig. A1.

From Fig. A1(a) $\psi_{cr} = \cos^{-1}\left(\frac{I}{J-.5}\right)$.

Exactly the same cases arise while determining r_{III} from equation (2.17). Here the only change is that I is replaced by (I-1) and θ_T and θ_S are replaced by θ_V and θ_U respectively.



THREE EXTREME CASES OF r_I

APPENDIX B

Determination of Polynomial Equations

While determining the polynomial equations it is to be noted that the deflection of a point depends upon the co-ordinates of the point, the non-dimensional flexural rigidity $\bar{D}$, the Poisson's Ratio of the plate material, μ, and the position of the load. So a general polynomial will consist of all the above mentioned variables. So that the polynomial does not become unmanageably complicated different polynomials have been determined for the thirteen sectors. The polynomial equations are determined as described below.

The present method gives the deflections at discrete points of the plate and the load positions also being discrete. The discrete points in both the cases being the node points, which, as pointed out earlier, are the central point of each element. So instead of trying to fit a least square polynomial it has been attempted to determine a polynomial which will give the exact deflection at these discrete node points. In the present analysis six radial positions has been taken. Thus for a particular $\bar{D}$, μ and load position the deflection is assumed as,

$$w = \sum_{i=o}^{5} C_i r^i$$

where r is the radial position of the element under consideration.

By using this equation for the six different r six simultaneous equations are obtained. By solving these, C's are determined.

Next C's are determined for a particular $\bar{D}$ and μ and for five different load positions. Next each of these C's are expressed as

$$C = \sum_{i=o}^{4} B_i L^i$$

where L is the load position. The B's are numbered 1 to 30 such that 1 to 5 are for C_o, 6 to 10 for C_1 and so on.

Next each of B's are expressed as,

$$B = \sum_{i=o}^{4} E_i \bar{D}^i$$

E's are numbered 1 to 150 in the same fashion as B.

Next each of E's are expressed as,

$$E = \sum_{i=o}^{4} F_i \mu^i$$

F's are numbered 1 to 750 such that 1 to 5 corresponds to E_1, 6 to 10 corresponds to E_2 and so on.

Thus 750 co-efficients for each sector are determined.

APPENDIX C

Computer Programs

There are two computer programs. The first one is to calculate the deflections and moments of the various elements by using the theoretical analysis method as described in section 2.4. The second program is used to determine the deflections of the various elements by using the co-efficients of the polynomial equations as described in section 3.4. A brief description of the programs is given below:

Program No.1 : This program as pointed out previously calculates the deflections and moments for the various elements of the plate. The program is perfectly general in the sense that it can be used to find the deflections and moments for any number of divisions of the plate (i.e. grid size), with a few minor changes in the dimension cards as will be pointed out as and when they appear. The program has been divided into various subroutines. The description of each subroutine is given below.

MAIN Program : The main program reads the input quantities and calls the various subroutines. All the print statements are also in this routine.

The input quantities are $\bar{D}, \mu$, number of sectors and number of radial divisions.

Subroutine GAMMA : This routine calculates the deflection co-efficients $\gamma(I,J,K)$ for the subgrade. In this program the first and third integrals of equation (2.25) are calculated by numerical integration using Simpson's Rule.

The input quantities in this program are the total number of sectors, number of radial divisions, number of sectors for which $\gamma(I,J,K)$ need to be calculated by using symmetry.

Subroutine TANINV : This subroutine is used to find out in which quadrants the angles θ_S, θ_T, θ_U, θ_V in equation (2.25) lies. This is needed because while calculating an angle from its tangent the computer gives the value in only two quadrants depending upon the sign of the tangent.

The input quantities are the numerator and denominator of the tangent.

Subroutine CHECK : This subroutine is used to get the proper sign of the parts under radical sign in equations (2.16) and (2.17) by using the method as described in Appexdix A.

The input quantities are the radial positions of the two elements for which $\gamma(I,J,K)$ is being calculated and the difference in their angle K.

Subroutine SIMPSN : This subroutine is used to calculate the first and the third integrals in equations (2.25) by using Simpson's Rule of numerical integration using 50 divisions.

The input quantities are the limits of the integration. The function to be integrated is defined inside the routine.

Subroutine MATGEN : This subroutine generates the co-efficient matrix. First it calculates the co-efficients for all the elements and then group them together. In this routine the dimension of Q will be the total number of elements including the imaginery elements.

The input quantities are γ (I,J,K), $\bar{D}$, μ, number of sectors and number of radial division.

Subroutine MATINV : This subroutine inverts the co-efficient matrix by using pivotal method of Gauss-Jordan[25]. The inverse of the matrix is stored in the memory in the place of the matrix and the original matrix is destroyed. In this routine the dimensions for PIVOT and IPIVOT and the first dimension for INDEX will be equal to the total number of elements for which the deflection has to be calculated, including the imaginary elements.

The input to this routine is the co-efficient matrix and the order of the matrix.

Subroutine DFLCTN : This subroutine calculates the deflections of the various elements. In this routine the proper dimensions for γ (I,J,K) has to be given in GAM and the dimension of BC, the vector on the right hand side of the set of simultaneous equations, is equal to the number of elements for which deflection has to be calculated.

The input quantities are the inverted co-efficient matrix, γ (I,J,K), number of sectors, number of radial divisions,

number of elements for which deflection is to be calculated, including the imaginary elements.

Subroutine MOMMR : This subroutine calculates the non-dimensional moments $\bar{M}_\rho$ from the non-dimensional diflections $\bar{w}$.

The input quantities are the deflections, the total number of sectors and radial divisions, total number of elements for which $\bar{M}_\rho$ is to be calculated and the total number of elements for which deflection has been calculated.

Subroutine MOMMT : This subroutine calculates the non-dimensional moments $\bar{M}_\theta$ from the non-dimensional deflections $\bar{w}$.

The input quantities are the same as routine MOMMR.

<u>Program No. 2</u> : As pointed out earlier this program is used to calculate the deflections of the various elements by using the polynomial equations. The method used in this program is nothing but just the inverse of the method used to determine the polynomial equations as described in Appendix B. Here the co-efficient F's for the particular sector is given as an input quantity. The program first calculates the co-efficients E's. After that it calculates the co-efficients B's and finally the co-efficients C's. From C's it calculates the deflections $\bar{w}$'s.

The input quantities are $\bar{D}, \mu$, the proper set of F, the radial position of the particular element, the position of the load.

A listing of both the programs is given in the next few pages.

COMPUTER PROGRAM NO. 1

```
BFTC  MAIN
      INTEGER RADIAL
      REAL MR
      REAL MT
      DIMENSION MT(78),MR(78)
      DIMENSION RADIAL(8)
      DIMENSION C(104,104),GAM(10,6,24),BC(104),W(104)
      DIMENSION O(192)

      ****************************************************************************
      N1=TOTAL NO OF SECTORS
      N2=TOTAL NO OF RADIAL DIVISIONS

      N3=NO OF SECTORS FOR WHICH CALCULATIONS OF GAM          IS NEEDED
      N4=NO OF SECTORS FOR WHICH CALCULATION OF W IS NEEDED
      N5=N2+2
      N6=N5*N4
      N7=NO OF ELEMENTS FOR WHICH MR AND MT IS TO BE CALCULATED
      N8=NO OF ELEMENTS FOR WHICH DEFLECTION IS TO CALCULATED
      DB=D̄
      AMU=μ
      ****************************************************************************

 05   FORMAT(50X,*ANALYSIS FOR LOAD AT RADIAL POSITION NO =*,I2,/50X,
     140(1H-))
 06   FORMAT(//////////62X,*THE DEFLECTHONS ARE*,/62X,19(1H-))
 08   FORMAT(//////////62X,*MOMENTS MRHO ARE*,/62X,19(1H-))
 10   FORMAT(//////////62X,*MOMENTS MTHETA ARE*,/62X,19(IH-))
 0    FORMAT(16X,102(1H-))
 08   FORMAT(7X,8(2X,*POSITION=*,I2,2X))
 14   FORMAT(1X,6E13.6)
 8    FORMAT(7X,*SECTOR=*,I3,1X,8E 4.7)
 17   FORMAT(24X,*MOMENT MTHETA*)
 15   FORMAT(20X,18(1H-))
 16   FORMAT(23X,34(1H-),/23X,*FOR LOAD AT RADIAL POSITION NO=*,I3,/23X,
     134(1H-))
 3    FORMAT(1H1)
 04   FORMAT(////48X,*ANALYSIS FOR DB=*,F6.3,*AND MU=*,F6.3,/48X,35(1H*
     1)
 12   FORMAT(20X,*DB=*,F6.3,*MU=*,F6.3)
      FORMAT(2F5.2)
      READ2,DB,AMU
      PRINT403
      PRINT404,DB,AMU
      PRINT403
      CALL GAMMA(6,13,10,24,GAM)
```

```
      DO 1 J=1,6
      DO 1 I=1,8
      DO 1 K=14,24
      IK=26-K
      GAM(I,J,K)=GAM(I,J,IK)
1     CONTINUE
      CALL MATGEN(6,8,13,24,104,GAM,C,DB,AMU)
      CALL MATINV(C,104,104)
      II=1
      IV=1
      DO 111 L=1,8
      RADIAL(L)=L
111   CONTINUE
      DO 43 IJKL=1,6
      PRINT405,II
      CALL DFLCTN(C,GAM,6,13,104,8,W)
      DO 106 J=1,6
      DO 106 N=1,13
      JN=(J-1)*13+N
      NJ=(N-1)*6+J
      BC(NJ)=W(JN)
106   CONTINUE
      PRINT406
      PRINT300
      PRINT108,(RADIAL(L),L=1,8)
      PRINT300
      JJ=1
      DO 46 K=1,13
      JJJ=JJ+7
      KK=JJJ-2
      PRINT48,K,(BC(KL),KL=JJ,KK)
      PRINT300
      JJ=JJ+8
46    CONTINUE
      PRINT403
      CALL MOMMR(W,6,13,104,78,MR)
      DO 424 J=1,6
      DO 424 N=1,13
      JN=(J-1)*13+N
      NJ=(N-1)*6+J
      BCM(NJ)=MR(JN)
424   CONTINUE
      PRINT408
      PRINT300
      PRINT300
      JJ=1
      DO 426 K=1,13
      JJJ=JJ+5
      PRINT48,K,(BCM(KL),KL=JJ,JJJ)
      PRINT300
      JJ=JJ+6
426   CONTINUE
```

```
      PRINT403
      CALL MOMMT(W,6,13,104,78,MT)
      DO 425 J=1,6
      DO 425 N=1,13
      JN=(J-1)*13+N
      NJ=(N-1)*6+J
      BCM(NJ)=MT(JN)
425   CONTINUE
      PRINT410
      PRINT300
      PRINT108,(RADIAL(L),L=1,8)
      PRINT300
      PRINT300
      JJ=1
      DO 427 K=1,13
      JJJ=JJ+5
      PRINT48,K,(BCM(KL),KL=JJ,JJJ)
      PRINT300
      JJ=JJ+6
427   CONTINUE
      PRINT403
      II=II+1
43    CONTINUE
      STOP
      END
```

```
$IB+TC  SUB1
      SUBROUTINE TANINV(A,B,C)
      PI=4.*ATAN(1.)
      IF(B.EQ..0) GO TO 1
      C=ATAN(ABS(A/B))
      IF(A) 2,3,3
3     IF(B) 4,5,5
5     GO TO 6
4     C=PI-C
      GO TO 6
2     IF(B) 7,8,8
8     C=-C
      GO TO 6
7       C=PI+C
      GO TO 6
1      IF(A.GE..0)C=PI/2.
      IF(A.LT..0)C=3.*PI/2.
  6   RETURN
      END
```

```
IBFTC  GAMMA
      SUBROUTINE GAMMA(N2,N4,N5,N1,GAM)
      DIMENSION GAM(N5,N2,N1)
      PI=4.*ATAN(1.)
      AL=2.*PI/FLOAT(N1)
      DO 1 I=1,N2
      DO 1 J=1,N2
      DO 1 K=1,N4
      A=FLOAT(I)
      FI=A
      B=FLOAT(J)-.5
      Z=FLOAT(I)-1.
      D=FLOAT(K)-1.
      AA=A*SIN((D-.5)*AL)
      BB=B-A*COS((D-.5)*AL)
      CC=Z*SIN((D-.5)*AL)
      DD=B-Z*COS((D-.5)*AL)
      EE=A*SIN((D+.5)*AL)
      FF=B-A*COS((D+.5)*AL)
      GG=Z*SIN((D+.5)*AL)
      HH=B-Z*COS((D+.5)*AL)
      CALL TANINV(AA,BB,TS)
      CALL TANINV(CC,DD,TV)
      CALL TANINV(EE,FF,TT)
      CALL TANINV(GG,HH,TU)
      E(G,T1,T2)=ALOG(TAN((G*AL+T1)/2.)/TAN((G*AL+T2)/2.))
      AD=D+.5
      AE=D-.5
      CALL CHECK(XA,TT,TS,A,B,FI,D)
      CALL CHECK(XC,TV,TU,Z,B,FI,D)
      XB=(B/(A-.5)) *SIN((D+.5)*AL)*E(AD,TT,TU)
      XD=(B/(A-.5))*SIN((D-.5)*AL)*E(AE,TV,TS)
      GAM(I,J,K)=XA+XB+XC+XD
    1 CONTINUE
      RETURN
      END
```

```
$IBFTC  MATGEN
      SUBROUTINE MATGEN(N2,N5,N3,N1,N6,GAM,C,DB,AMU)
      DIMENSION C(N6,N6),GAM(N5,N2,N1)
      DIMENSION Q(192)
      DO 10 J=1,N2
      DO 10 N=1,N3
      DO 18 I=1,N5
      DO 18 IV=1,N1
      K=INT(ABS(FLOAT(IV)-FLOAT(N))+1.)
      K1=K-1
      K2=K-2
      IF(K.EQ.1) GO TO 13
      GO TO 14
 13   K1=N1
      K2=N1-1
 14   IF(K.EQ.2) K2=N1
      K6=K+1
      IF(K6.GT.N1) K6=K6-N1
      K7=K+2
      IF(K7.GT.N1) K7=K7-N1
 16   JN=(J-1)*N3+N
      IIV=(I-1)*N1+N
      F=FLOAT(I)
      C3=(F-.5)*(6.+6./(((F-.5)**4)*(AL**4))+8./(((F-.5)**2)*(AL**2))-
     18./(((F-.5)**4)*(AL**2))+2./((F-.5)**2))
      C4=(F+.5)*(-4.-4./(((F+.5)**2)*(AL**2))+2./(F+.5)-2./(((F+.5)**3*)
     1(AL**2))-1./((F+.5)**2)-1./(2.*((F+.5)**3)))
      C5=(F+1.5)*(1.-1./(F+1.5))
      C8=(F-.5)*(1./(((F-.5)**4)*(AL**4)))
      C9=(F-.5)*(-4./(((F-.5)**4)*(AL**4))-4./(((F-.5)**2)*(AL**2))+
     14./(((F-.5)**4)*(AL**2)))
      C12=(F+.5)*(2./(((F+.5)**2)*(AL**2))+1./(((F+.5)**3)*(AL**2)))
      IF(I.EQ.1) GO TO 11
      C2=(F-1.5)*(-4.-4./(((F-1.5)*AL)**2)-2./(F-1.5)+2./(((F-1.5)**3)**
     1(AL**2))-1./((F-1.5)**2)+1./(2.*((F-1.5)**3)))
      C6=(F-1.5)*(2./(((F-1.5)*AL)**2)-1./(((F-1.5)**3)*(AL**2)))
      IF(I.EQ.2) GO TO 12
      C1=(F-2.5)*(1.+1./(F-2.5))
      Q(IIV)=(C1*GAM(I-2,J,K)+C2*(GAM(I-1,J,K))+C3*GAM(I,J,K)+C4*GAM
     1(I+1,J,K)+C5*GAM(I+2,J,K)+C6*(GAM(I-1,J,K6)+GAM(I-1,J,K1))+C8*
     2(GAM(I,J,K7)+GAM(I,J,K2))+C9*(GAM(I,J,K6)+GAM(I,J,K1))+C12*(GAM
     3(I+1,J,K6)+GAM(I+1,J,K1)))*DB
      GO TO 18
 12   C1=(1.-1./(F-1.5))*(F-1.5)
      K3=K+12
      IF(K3.GT.N1) K3=K3-N1
      Q(IIV)=(C1*GAM(I-1,J,K3)+C2*GAM(I-1,J,K)+C3*GAM(I,J,K)+C4*GAM
     1(I+1,J,K)+C5*GAM(I+2,J,K)+C6*(GAM(I-1,J,K6)+GAM(I-1,J,K1))+C8*
     2(GAM(I,J,K7)+GAM(I,J,K2))+C9*(GAM(I,J,K6)+GAM(I,J,K1))+C12*(GAM
     3(I+1,J,K6)+GAM(I+1,J,K1)))*DB
```

```
      GO TO 18
11    C1=(F+.5)*(1.-1./(F+.5))
      C2=(F-.5)*(-4.-4./(((F-.5)*AL)**2)+2./(F-.5)-2./(((F-.5)**3)*
     1(AL**2))-1./((F-.5)**2)-1./(2.*((F-.5)**3)))
      C6=(F-.5)*(2./(((F-.5)*AL)**2)+1./(((F-.5)**3)*(AL**2)))
      K3=K+12
      IF(K3.GT.N1) K3=K3-N1
      K4=K+11
      IF(K4.GT.N1) K4=K4-N1
      K5=K+13
      IF(K5.GT.N1) K5=K5-N1
      Q(IIV)=(C1*GAM(I+1,J,K3)+C2*GAM(I,J,K3)+C3*GAM(I,J,K)+C4*GAM
     1(I+1,J,K)+C5*GAM(I+2,J,K)+C6*(GAM(I,J,K4)+GAM(I,J,K5))+C8*
     2(GAM(I,J,K7)+GAM(I,J,K2))+C9*(GAM(I,J,K6)+GAM(I,J,K1))+C12*(GAM
     3(I+1,J,K[illegible])+GAM(I+1,J,K1)))*DB
18    CONTINUE

      ***************************************************************
      GROUPING OF THE COEFFICIENTS
      THIS PART OF THE PROGRAM HAS TO BE CHANGED ACCORDING TO THE PROBLEM
      ***************************************************************

      DO 5000 I=1,
      DO 5000 IV=1,13
      IV1=26-IV
      IIV=(I-1)*13+IV
      IIV1=(I-1)*24+IV1
      IIV2=(I-1)*24+IV
      IF(IV.EQ.1.OR.IV.EQ.13) GO TO 5001
      C(JN,IIV)=Q(IIV2)+Q(IIV1)
      GO TO 114
5001  C(JN,IIV)=Q(IIV2)
114   IF(JN.EQ.IIV) C(JN,IIV)=C(JN,IIV)+1.
5000  CONTINUE
10    CONTINUE
      A=FLOAT(N2)
      NA=N2
      N7=N2+1
      DO 21 N=1,N3
      DO 21 J=N7,N5
      JN=(J-1)*N3+N
      IV=N
      IIV1=(NA+1)*N3+IV
      IIV2=NA*N3+IV-1
      IIV3=NA*N3+IV
      IIV4=NA*N3+IV+1
      IIV5=(NA-1)*N3+IV
      IIV6=(NA-1)*N3+IV+1
      IIV7=(NA-2)*N3+IV
      IIV8=(NA-1)*N3+IV-1
      IF(J.EQ.N5) GO TO 24
      IIV1=(NA+1)*13+IV
      IIV2=NA*13+IV-1
      IIV3=NA*13+IV
```

```
      IIV4=NA*13+IV+1
      IIV5=(NA-1)*13+IV
      IIV6=(NA-1)*13+IV+1
      IIV7=(NA-2)*13+IV
      IIV8=(NA-1)*13+IV-1
      IF(J.EQ.8) GO TO 24
      C(JN,IIV1)=.5
      C(JN,IIV5)=-.5-AMU/A-AMU/((A*AL)**2)
      C(JN,IIV7)=.5
      C(JN,IIV3)=-.5+AMU/A-AMU/((A*AL)**2)
      IF(IV.EQ.13) GO TO 22
      IF(IV.EQ.1) GO TO 23
      C(JN,IIV2)=AMU/(2.*((A*AL)**2))
      C(JN,IIV4)=C(JN,IIV2)
      C(JN,IIV6)=C(JN,IIV2)
      C(JN,IIV8)=C(JN,IIV2)
      GO TO 21
22    C(JN,IIV8)=AMU/((A*AL)**2)
      C(JN,IIV2)=AMU/((A*AL)**2)
      GO TO 21
23    C(JN,IIV6)=AMU/((A*AL)**2)
      C(JN,IIV4)=CUJN,IIV6)
      GO TO 21
24    C(JN,IIV1)=1.+1./(2.*A)
      C(JN,IIV3)=-3.-1./(2.*A)-1./(A**2)-2.*(2.-AMU)/((A*AL)**2)
     1+(3.-AMU)/((A**3)*(AL**2))
      C(JN,IIV5)=3.-1./(2.*A)+1./(A**2)+2.*(2.-AMU)/((A*AL)**2)
     1+(3.-AMU)/((A**3)*(AL**2))
      C(JN,IIV7)=-1.+1./(2.*A)
      IF(IV.EQ.13) GO TO 25
      C(JN,IIV4)=(2.-AMU)/((A*AL)**2)-(3.-AMU)/(2.*(A**3)*(AL**2))
      C(JN,IIV6)=-(2.-AMU)/((A*AL)**2)-(3.-AMU)/(2.*(A**3)*(AL**2))
      IF(IV.EQ.1) GO TO 26
      C(JN,IIV2)=C(JN,IIV4)
      C(JN,IIV8)=C(JN,IIV6)
      GO TO 21
26    C(JN,IIV6)=C(JN,IIV6)*2.
      C(JN,IIV4)=C(JN,IIV4)*2.
      GO TO 21
25    C(JN,IIV2)=(2.-AMU)/((A*AL)**2)-(3.-AMU)/(2.*(A**3)*(AL**2))
      C(JN,IIV8)=-(2.-AMU)/((A*AL)**2)-(3.-AMU)/(2.*(A**3)*(AL**2))
      C(JN,IIV2)=C(JN,IIV2)*2.
      C(JN,IIV8)=C(JN,IIV8)*2.
21    CONTINUE
      RETURN
      END
```

```
$IBFTC  MATINV
      SUBROUTINE MATINV(A,N,NN)
      DIMENSION A(NN,NN),PIVOT(104),IPIVOT(104),INDEX(104,2)
      EQUIVALENCE (IROW,D1,JROW),(ICOLUM,D2,JCOLUM),(AMAX,T,SWAP)
      IF ( N-2 ) 11,12,15
   11 A( N,N)=1.0/A( N,N)
      RETURN
   12 D1=A(1,1)*A(2,2)-A(1,2)*A(2,1)
      D2=A(1,1)
      A(1,1)=A(2,2)/D1
      A(2,2)=D2/D1
      A(2,1)=-A(2,1)/D1
      A(1,2)=-A(1,2)/D1
      RETURN
C**      INITIALIZATION
   15 DO 20  J=1,N
   20 IPIVOT(J)=0
      DO 550 I=1,N
C**     SEARCH FOR PIVOT ELEMENT
      AMAX= .0
      DO 105 J=1,N
      IF (IPIVOT(J)-1) 60,105,60
   60 DO 100 K=1,N
      IF (  IPIVOT(K)-1) 80,100,740
   80 IF (  ABS(AMAX)-ABS(A(J,K)) ) 85,100,100
   85 IROW=J
      ICOLUM=K
      AMAX=A(J,K)
  100 CONTINUE
  105 CONTINUE
      IPIVOT(ICOLUM)=IPIVOT(ICOLUM)+1
C**   INTERCHANGE ROWS TO PUT PIVOT ELEMENT ON DIAGONAL
      IF (  IROW-ICOLUM) 150,260,150
  150 DO 200 L=1,N
      SWAP=A(IROW,L)
      A(IROW,L)=A(ICOLUM,L)
  200 A(ICOLUM,L)=SWAP
  260 INDEX(I,1)=IROW
      INDEX(I,2)=ICOLUM
      PIVOT(I)=A(ICOLUM,ICOLUM)
C**    DIVIDE PIVOT ROW BY PIVOT ELEMENT
      A(ICOLUM,ICOLUM)=1.0
      DO 350 L=1,N
  350 A(ICOLUM,L)=A(ICOLUM,L)/PIVOT(I)
C**   REDUCE NON-PIVOT ROWS
  380 DO 550 L1=1,N
      IF ( L1-ICOLUM ) 400,550,400
  400 T=A(L1,ICOLUM)
      A(L1,ICOLUM)=0.0
```

```
      DO 450 L=1,N
  450 A(L1,L)=A(L1,L)-A(ICOLUM,L)*T
  550 CONTINUE
C**   INTERCHANGF COLUMN
      DO 710 I=1,N
      L=N-I +1
      IF ( INDEX (L,1) - INDEX(L,2) ) 630,710,630
  630 JROW=INDEX(L,1)
      JCOLUM=INDEX(L,2)
      DO 705 K=1,N
      SWAP=A(K,JROW)
      A(K,JROW)=A(K,JCOLUM)
  705 A(K,JCOLUM)=SWAP
  710 CONTINUE
  740 RETURN
      END



$IBFTC  CHECK
      SUBROUTINE CHECK(G,A,B,C,D,FI,F)
      PI=4.*ATAN(1.)
      AL=PI/12.
      E=C/D
      IF(E.LF.1.) GO TO 1
      INDEX=1
      GO TO 2
 1    PSCR=ARCOS(E)
      PS1=(F+.5)*AL
      PS2=(F-.5)*AL
      IF(PS1.GT.PSCR.AND.ABS(PS2).LT.PSCR) GO TO 3
      IF(PS1.LE.PSCR) INDEX=-1
      IF(ABS(PS2).GE.PSCR) INDEX=1
 2    CALL SIMPSN(G,A,B,C,D,FI,INDEX)
      GO TO 4
 3    TCR=ARSIN(E)
      INDEX=1
      CALL SIMPSN(G2,TCR,B,C,D,FI,INDEX)
      INDEX=-1
      CALL SIMPSN(G1,A,TCR,C,D,FI,INDEX)
      G=G1+G2
 4    RETURN
      END
```

```
$IBFTC  SIMPSN
      SUBROUTINE SIMPSN(G,A,B,C,D,FI,INDEX)
      IF(A.EQ.B) GO TO 3
      Y=(D/C)**2
      F(T)=FLOAT(INDEX)*SQRT(1.-Y*(SIN(T)**2))
      DIV=50.
      H=(B-A)/DIV
      X=A
      N=INT(DIV/2.)
      SUM=0.
      DO 2 I=1,N
      SUM=SUM+(H/3.)*(F(X)+4.*F(X+H)+F(X+2.*H))
      X=X+2.*H
 2    CONTINUE
      G=C*SUM/(FI-.5)+D*(SIN(B)-SIN(A))/(FI-.5)
      GO TO 4
 3    G=0.
 4    RETURN
      END
```

```
$IBFTC MOMMR
      SUBROUTINE MOMMR(W,N2,N3,N8,N7,MR)
      REAL MR
      DIMENSIONMR(N7),W(N8)
      DO 401 IV=1,N3
      DO 401 I=1,N2
      IV1=IV-1
      IF(IV.EQ.1) IV1=2
      IV2=IV+1
      IF(IV.EQ.N3) IV2=N3-1
      IIV=(I-1)*N3+IV
      IIV1=I*13+IV
      IIV2=(I-2)*N3+IV
      IIV3=(I-1)*N3+IV1
      IIV4=(I-1)*N3+IV2
      FI=FLOAT(I)-.5
      IF(I.EQ.1) GO TO 402
      MR(IIV)=-DB*(W(IIV1)*(1.+AMU/(2.*FI))+W(IIV)*(-2.-2.*AMU/((FI*AL))
     1**2))+W(IIV2)*(1.-AMU/(2.*FI))+(W(IIV3)+W(IIV4))*AMU/((FI*AL)**2))
      GO TO 401
 402  IV3=IV+12
      IF(IV3.GT.N3) IV3=N3-(IV3-N3)
      IIV5=(I-1)*N3+IV3
      MR(IIV)=-DB*(W(IIV1)*(1.+AMU/(2.*FI))+W(IIV)*(-2.-2.*AMU/((FI*AL))
     1**2))+W(IIV5)*(1.-AMU/(2.*FI))+(W(IIV3)+W(IIV4))*AMU/((FI*AL)**2))
 401  CONTINUE
      RETURN
      END
```

```
IBFTC  MOMMT
      SUBROUTINE MOMMT(W,N2,N3,N8,N7,MT)
      REAL MT
      DIMENSION MT(N7),W(N8)
      DO 401 IV=1,N3
      DO 401 I=1,N2
      IV1=IV-1
      IF(IV.EQ.1) IV1=2
      IV2=IV+1
      IF(IV.EQ.N3) IV2=N3-1
      IIV=(I-1)*N3+IV
      IIV1=I*13+IV
      IIV2=(I-2)*N3+IV
      IIV3=(I-1)*N3+IV1
      IIV4=(I-1)*N3+IV2
      FI=FLOAT(I)-.5
      IF(I.EQ.1) GO TO 402
      MT(IIV)=-DB*(W(IIV1)*(1./(2.*FI)+AMU)+W(IIV)*(-2./((FI*AL)**2)-2.*
     1AMU)+W(IIV2)*(-1./(2.*FI)+AMU)+(W(IIV3)+W(IIV4))/((FI*AL)**2))
      GO TO 401
 Q2   IV3=IV+12
      IF(IV3.GT.N3) IV3=N3-(IV3-N3)
      IIV5=(I-1)*N3+IV3
      MT(IIV)=-DB*(W(IIV1)*(1./(2.*FI)+AMU)+W(IIV)*(-2./((FI*AL)**2)-2.*
     1AMU)+W(IIV5)*(-1./(2.*FI)+AMU)+(W(IIV3)+W(IIV4))/((FI*AL)**2))
 01   CONTINUE
      RETURN
      END


BFTC  DFLCTN
      SUBROUTINE DFLCTN(C,GAM,N2,N3,N6,N5,W)
      DIMENSION GAM(10,8,24)
      DIMENSION BC(130)
      DIMENSION C(N6,N6),W(N6)
      DO 42 J=1,N2
      DO 42 N=1,N3
      JN=(J-1)*N3+N
      K=INT(ABS(FLOAT(IV)-FLOAT(N))+1.)
      BC(JN)=GAM(II,J,K)
 2     CONTINUE
      DO 44 J=1,N2
      DO 44 N=1,N3
      JN=(J-1)*N3+N
      W(JN)=0.
      DO 44 M=1,N6
      W(JN)=W(JN)+C(JN,M)*BC(M)
 4    CONTINUE
      RETURN
      END
```

COMPUTER PROGRAM NO. 2

```
      R=RADIAL POSITION
      ISEC=SECTOR NO.
      LP=LOAD POSITION
      DIMENSION F(750),E(150),D(30),C(6),W(7)
1     FORMAT(I1)
3     FORMAT(I2)
4     FORMAT(10X,5E12.5)
2     FORMAT(2F5.2)
16    FORMAT(//20XT2F5.2)
100   FORMAT(F5.2)
      READ100,R
      READ1,LP
      READ3,ISEC
      READ4,(F(I),I=1,750)
      READ2,DB,AMU
      PRINT16,DB,AMU
      DO 5 I=1,150
      E(I)=0.
      DO 5 L=1,5
      K=L-1
      IJ=(I-1)*5+L
      E(I)=E(I)+F(IJ)*(AMU**K)
5     CONTINUE
      DO 6 I=1,30
      D(I)=0.
      DO 6 J=1,5
      K=J-1
      IJ=(I-1)*5+J
      D(I)=D(I)+E(IJ)*(DB**K)
6     CONTINUE
      A=FLOAT(LP)
      DO 7 I=1,6
      C(I)=0.
      DO 7 J=1,5
      IJ=(I-1)*5+J
      K=J-1
      C(I)=C(I)+D(IJ)*(A**K)
7     CONTINUE
      W(I)=0.
      DO 8 J=1,6
      K=J-1
      W(I)=W(I)+C(J)*(R**K)
      PRINT10
      PRINT9,ISEC
9     FORMAT(//55X,*FOR ELEMENTS IN SECTOR=*,I2,//)
10     FORMAT(1H1)
      PRINT11,(W(I),I=1,7)
11    FORMAT(10X,7E15.6)
15    CONTINUE
14    CONTINUE
      PRINT10
      STOP
```